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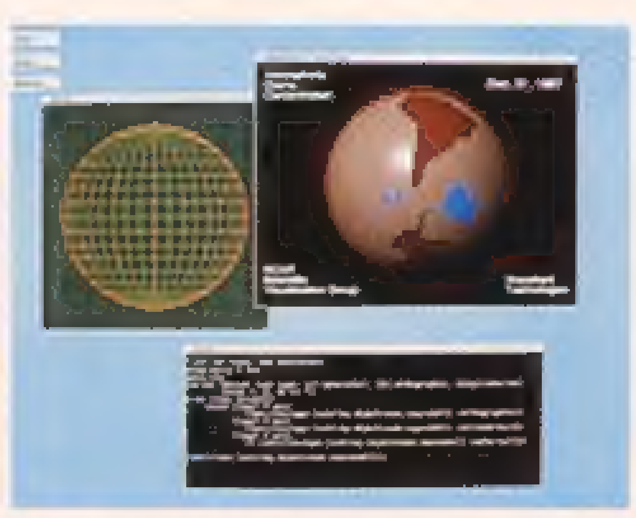

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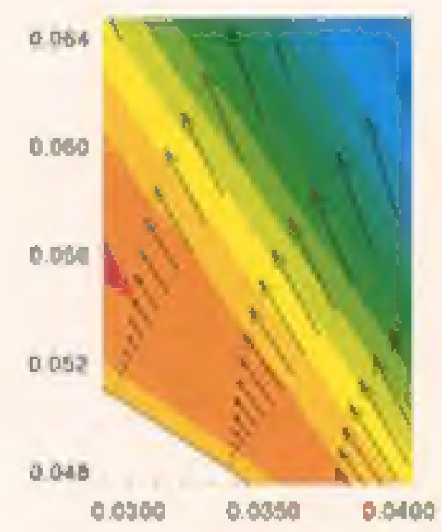

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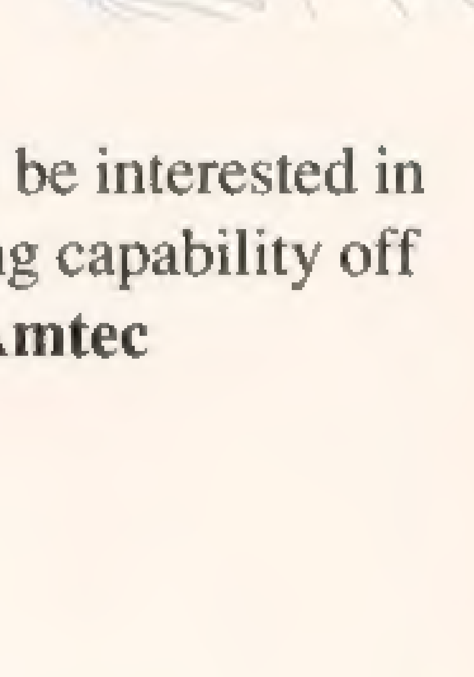

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ON THE COVER

A model of a submarine on a soundstage at Lucasfilm's Industrial Light & Magic. Turbulence, bubbles and underwater particles, and the wakes of attacking torpedoes were generated by ILM's Computer Graphics department and then composited with the footage of the models to create a convincing undersea illusion. Photo copyright 1989 Industrial Light & Magic.

ABOUT THIS ISSUE

The Art of Science and the Science of Art

It seems certain that the future will bring with it a convergence of science and art, two areas of discipline that have heretofore been polar opposites. The advent of visual processing has made it possible for members of these two divergent schools to develop a new appreciation for each other and to view their work from an entirely new perspective — each from the point of view of the other.

Physicists, chemists, and engineers have traditionally been more numerically than visually oriented. The opposite has typically been true of artists (Leonardo daVinci may be the most famous exception to these two statements). Present technology makes it possible for scientists to create three-dimensional visual expressions of their equations. This can remove much of the mathematical abstraction of a concept and make complex scientific ideas more accessible to a lay audience. On the other hand, an artist, such as a sculptor, using the graphic computer as an integral part of the creative process, may discover a new aesthetic in the mathematical underpinnings of undulating surfaces and curving forms.

In "The Art of Thermodynamics" Kenneth Jolls, a chemical engineer, extolls the "artistic beauty" of three dimensional images he has created to illustrate the structure and logic of thermodynamics. Sculptor Stewart Dickson, author of "Manufacturing the Impossible Soap Bubble," takes a mathematical approach to his sculpture and produces the original mathematics from which it is derived. Dr. Court Cutting's "Putting a Human Face on Computers" details how computer-aided planning is making significant breakthroughs in unifying the science and art of reconstructive surgery. And Crispin Littlehale's "The Undersea World of Industrial Light and Magic," delves into visual processing's role in that most diverting of industrial art forms: filmmaking.

Mr. Dickson, the sculptor, claims that the "graphical computer has made artists out of mathematicians." Mr. daVinci might feel right at home.

— Douglas Cruickshank, Editor

ERRATA

In the last issue (*IRIS Universe* No. 11) the article on *PowerVision* entitled "Imitating Life," incorrectly referred to the accumulation buffer as *FlexScene*. The correct name for the *PowerVision* accumulation buffer is *SharpScene*™.

Also in the last issue, due to a production error, two sentences were misplaced in Laurence Feldman's "The Right Tools for the Task." The last two sentences of the second to last paragraph in the article should correctly read: "A ray-traced image developed for the Cray series computers will also be used to render airplane and flow field data. All of the above techniques employed multiple light sources and produced 24 bit r,g,b images." Our apologies to Mr. Feldman and our readers.

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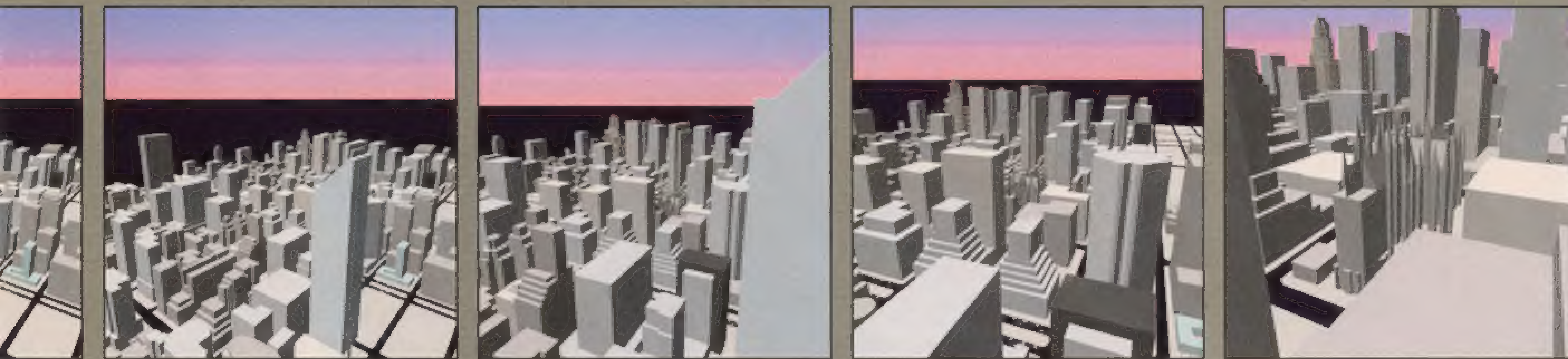
SEQUENCE

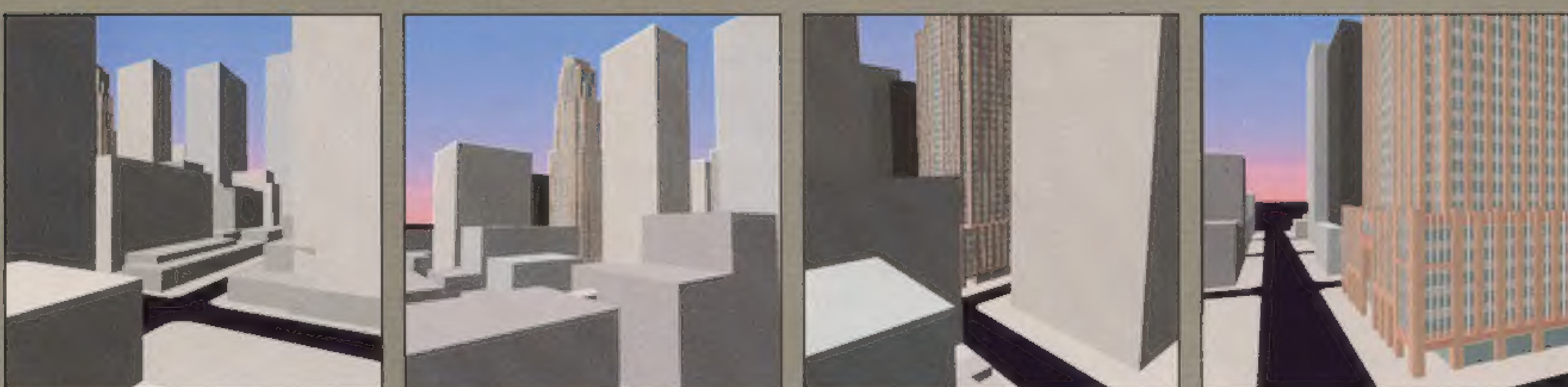
By Benjamin Garlick, Daniel Baum, and James Winget



When writing graphics applications, one commonly relies solely on the power of the Geometry Pipeline™ to speed the graphics display tasks. With SGI's Power Series line of multiprocessing workstations, one can boost graphics performance using host parallel processing in conjunction with the graphics acceleration provided by the Geometry Pipeline.

This image sequence is the output of a viewing program that relies on both parallel processing and the Geometry Pipeline to view very large databases at interactive rates. The model of midtown Manhattan, which was designed by Swanke Hayden Connell Architects of New York City, contains over 150,000 polygons.

To achieve interactive walk-throughs of the Manhattan database, the viewing program first spatially subdivides the 3D database into many small volumes. The environment is subdivided such that each volume contains roughly an equal number of polygons. Using a parallel culling algorithm, this viewing tool utilizes the current view position and direction to determine which of these volumes are contained within the field of view. Only the polygons contained within these "visible" volumes are

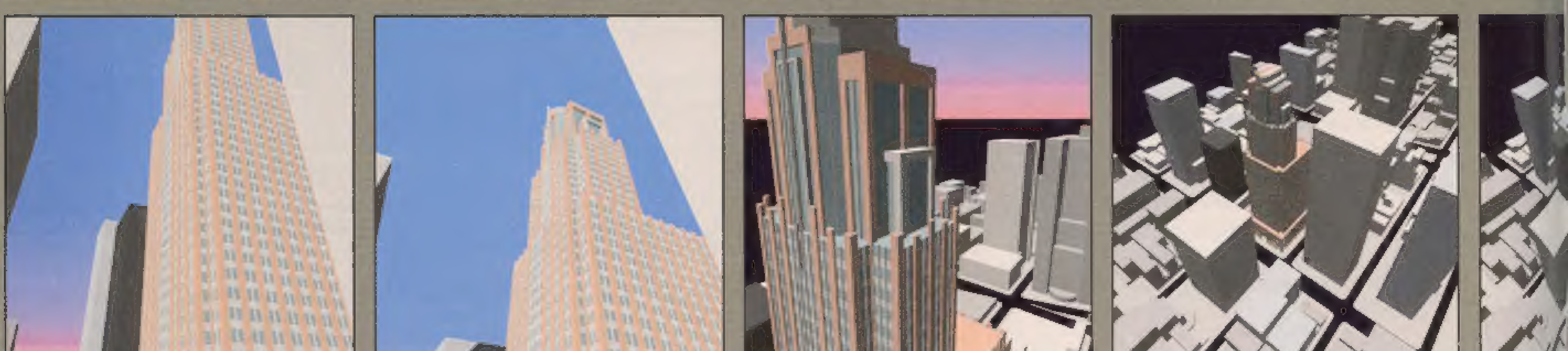


potentially visible. The parallel processes then discard polygons which are backfacing and send remaining polygons to the Geometry Pipeline for display.

Since the Geometry Pipeline does not have to discard backfacing and out-of-view polygons itself, it spends most of its time rendering only those polygons which contribute to the final scene. If the viewer is positioned in the middle of the model, more than half of the polygons are outside the field of view, and about half of the remaining polygons are backfacing, thus Geometry Pipeline needs to render less than one quarter of the scene. This gives more than a four-fold increase in display rate which enables one to fly through midtown Manhattan at about four frames per second.

The Geometry Pipeline is fast, and with the help of host parallel processing it can be used very efficiently to further enhance performance, because where there is a need for speed, there is always a need for MORE speed.

Benjamin Garlick is a member of the Technical Staff; Daniel Baum is Manager, Graphics Software; James Winget is Principal Scientist. All work in the Advanced Systems Division, Silicon Graphics.



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SOLUTIONS

Backface Culling for Animation

By Jack Moran

A good animation sequence requires that the frame rate be as high as possible. Frame rate is dependent upon such factors as draw speeds, screen-clear time, fill rate, display-list traversal time, quad-word alignment, and other factors. Typically, animations are accomplished by a separate list of polygons representing each frame of the animation. Here we present a method that reduces the amount of polygon data that needs to be processed during the animation sequence.

The basic concept is to pre-cull backfacing polygons before they are sent to the graphics subsystem. This reduces the quantity of data that needs to be processed by approximately 50 percent. We do this pre-culling for all frames in the animation in a software algorithm every time the view is changed, because the lists become invalid with each new view.

Assume that each polygon in a frame's display-list is associated with a visibility flag. If the view remains the same for the duration of the animation, only those polygons with visibility enabled are drawn. Otherwise, if the view has changed, the visibility test is not performed, and *all* polygons are sent to the graphics subsystem.

On a multiprocessor machine, the maintenance of the visibility flags may be assigned to separate processing (see pseudo-code fragment). On uniprocessor machines, the pre-backface culling could be performed as soon as the view is no longer actively changing.

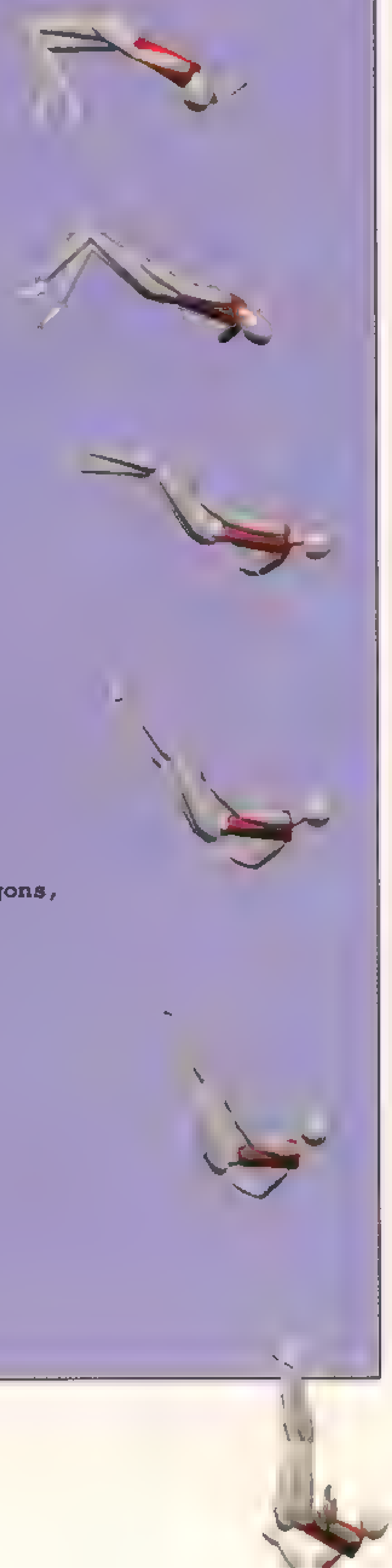
A variation on this theme would be to maintain two display-lists (or two polygon pointer lists). List A would be the master list and list B would be a shorter list of polygons with the backfaced polygons removed. While this option may use more memory, the traversal algorithm is simplified because the visibility test is no longer necessary.

Actual performance gains may vary on different system architectures depending on the location of system bottlenecks.

The images for this article were generated by the program COMPAMM which was developed by the Centro De Estudios e Investigaciones Tecnicas De Guipuzcoa (CEIT). This package is used for kinematic and dynamic analysis of machines and mechanisms. Animation performance was doubled due to pre-backface culling.

Jack Moran is a systems engineer at Silicon Graphics.

```
        struct {
                int *frame_head;
                Boolean cull_valid;
                } animation [NFRAMES];

main()
{
        /* for simplicity, assume each frame in the animation is a list of polygons
where animation[i].frame_head points to the head of the list for frame i. */

        new_viewing_flag = TRUE; child_settled = FALSE; parent_pid = getpid();
        cull_pid = sproc(culling_proc,PR_SALL,animation);

        /* Allow child to initialize before continuing */
        while(!child_settled) sginap(1);

        while(TRUE) {
                /* process input events */
                ReadQueue(&view_changed);
                if(view_changed) {
                        /* put new viewing matrix onto graphics
                           stack and re-initialize viewing_matrix */

                        /* wake up child process to do culling */
                        kill(SIGINTR,cull_pid);
                }
                frame = (frame++) % NFRAMES; draw_scene(animation,frame);
        }
}
draw_scene(animation,frame)
{
        if( animation[frame].cull_valid ) {
                /* draw polygon list testing visibility flag at each polygon */
        } else {
                /* draw all polygons in list without testing visibility */
        }
}
culling_proc(animation)
        /* Process running in parallel to do backface removal of the polygon lists */
{
        int i;
        extern intrhnd();

        sigset(SIGINTR,intrhnd);
        setblockproccnt(parent_pid,0);
        sigsetjmp(jump_point, . . .);    /* available at IRIX 3.3 */
        child_settled = TRUE;
        while(TRUE) {
                if( !new_viewing_flg ) {
                        pause(); /* wait until there is work to do */
                }
                for(i=0;i<NFRAMES;i++) {
                        /* using latest viewing_matrix, cullout the backfacing polygons,
setting visibility flag at each polygon to TRUE or FALSE */
                        animation[i].cull_valid = TRUE;
                        }
                }
                new_viewing_flg = FALSE;
        }
}
intrhnd()
{
        blockproc(parent_pid);
        new_viewing_flg = TRUE;
        for(i=0;i<NFRAMES;i++) animation[i]cull_valid = FALSE;
        unblockproc(parent_pid);

        /* jump back to restart culling all frames */
        siglongjmp(jump_point, . . .); /* available at IRIX 3.3 */
}
```



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PUTTING A HUMAN FACE ON COMPUTERS

Three dimensional computer simulations are helping to unify the art and science of reconstructive craniofacial surgery.

BY COURT CUTTING, M.D.

For the past several years the Institute of Reconstructive Plastic Surgery at New York University Medical Center has utilized visual processing for developing computer-aided planning of craniofacial surgery. In craniofacial surgery, bones of the skull are sectioned and then repositioned to improve the appearance of patients with severe facial bone malformations. The surgery usually takes place with the aid of a neurosurgeon, who performs a frontal craniotomy and retracts the brain away from the facial bones. This allows the bones to be cut and repositioned by the plastic surgeon.

Two important considerations make computer-aided planning extremely useful. First, in the past, the surgery has been approached as an experience in sculpture. Unlike sculpture on more conventional media, facial soft tissue grows and swells markedly in response to injury. Consequently, the artistic method tends to break down in craniofacial surgery. The typical procedure usually begins with an incision made across the top of the scalp, to avoid scarring on the face. The soft tissue is then retracted down and away from the bone and the surgery proceeds. By the middle of the operation, the facial soft tissue is very swollen making it difficult to judge the aesthetic effect of the movements of the underlying bones.

Secondly, it is no longer acceptable to wait for children with these conditions to mature

before performing corrective surgery. The psycho-social damage caused by growing up with severe facial malformations is frequently irreversible. Therefore, surgery is usually begun in infancy. However, from a surgical planning perspective, the problem now becomes four-dimensional sculpture; future growth patterns must be factored into the planning equation. For these reasons computer graphics methods have been employed to increase the precision of the surgical planning process.

I have directed this project in association with Drs. Marilyn Noz, Robert Hummel, Ken Perlin and their graduate students, Alan Kalvin and Betsy Haddad. Corporate Marketing at Silicon Graphics played a significant part in facilitating the work by arranging SGI's loan of an IRIS 4D/70GT.

Surgical planning was originally done using only thirty points on the surface of the skull. The points were located by triangulating simple frontal and lateral X-rays. The program was first written on a personal computer. It allowed the user to simulate surgery graphically in three dimensions on a wire frame image and have the computer automatically position the bone fragments to best approximate "normal." Normal was defined by averaging a normative data set corrected for age, race, and sex. The project was then extended to 3D computerized tomographic (CT) images using SGI's IRIS 2400.

Although the first image was crude, the idea's viability was clearly demonstrated. As clinical experience with the two methods grew, the earlier method proved more useful. The reason for this was that the first program included an optimization step which allowed the computer to automatically position the skull bone fragments to best fit normal. The CT based simulation lacked this essential ingredient.

For this reason work was begun on a quantitative, metric system which could be applied to body surfaces sampled from CT or magnetic resonance (MR) scans. As a first step in this direction a topologically connected three dimensional surface model had to be created from CT data. The data structure used was the winged edge representation. A new segmentation algorithm was employed to find the bone boundries at the skull surface and place the data into winged edge format.

The topological connectivity is essential for the rapid acquisition of points in a local neighborhood. This allows neighboring points to be fit to continuous surfaces for computations of principal curvatures and directions which form the basis of the metric system now being developed.

A normal human skull rendered on a Silicon Graphics 4D workstation

Armed with this new metric system, optimizations of bone fragment position could be based on thousands of surface points rather than just a few.

The research group at NYU feels strongly that the metric system under development has implications which extend far beyond plastic surgery. The parametric surface model could also form a rational basis for the statistical analysis of volume data. The volume data from a CT or MR examination could be compared to a database of normals corrected for age, race and sex, and the statistically significant abnormalities pointed up to the clinician with color coding. Although this last direction is science fiction at this time — today's most powerful workstation could not handle such an application — the theoretical foundation is promising. In coming years, as the capabilities of workstations approach those of supercomputers, these applications will become tractable.

Dr. Court Cutting is Assistant Professor of Plastic Surgery at the Institute of Reconstructive Plastic Surgery, New York University Medical Center.

TIME-SLICED VISUALIZATION

The Graphical Animation Software system, originally developed for meteorologists, has the potential for broad scientific use.

BY ALAN DAVIS

Florida State University's Graphical Animation Software system, is capable of producing and viewing from 1 to 10,000 frames of animation. The display system allows for the visualization, both spatially and temporally, of the massive amounts of data produced by fluid field numerical modeling. The system is part of Silicon Graphics' IRIS Software Exchange program. To initialize the Graphical Animation Software system, a library of FORTRAN subroutines is called by the user's application. The system then generates a sequence of frames representing the application output at different time steps. Because the display system is stored as graphical metacode, this process of taking "snapshots" proceeds independently of the visualizations themselves.

When the time comes to produce the images, a rendering program translates the metacode into device-specific graphical instructions for display on an SGI workstation. This step is run interactively, with the user being able to control many aspects of the display. Output can be redirected to an NTSC encoder for display on a television, or can be stored on tape for VCR replay. Any 2D or 3D time-varying spatial database can be displayed using the Graphical Animation Software system, with color values denoting the intensity of a field. Meanwhile, temporal changes in the fields can be displayed as a sequence of still frames at a maximum rate of two to three per second.

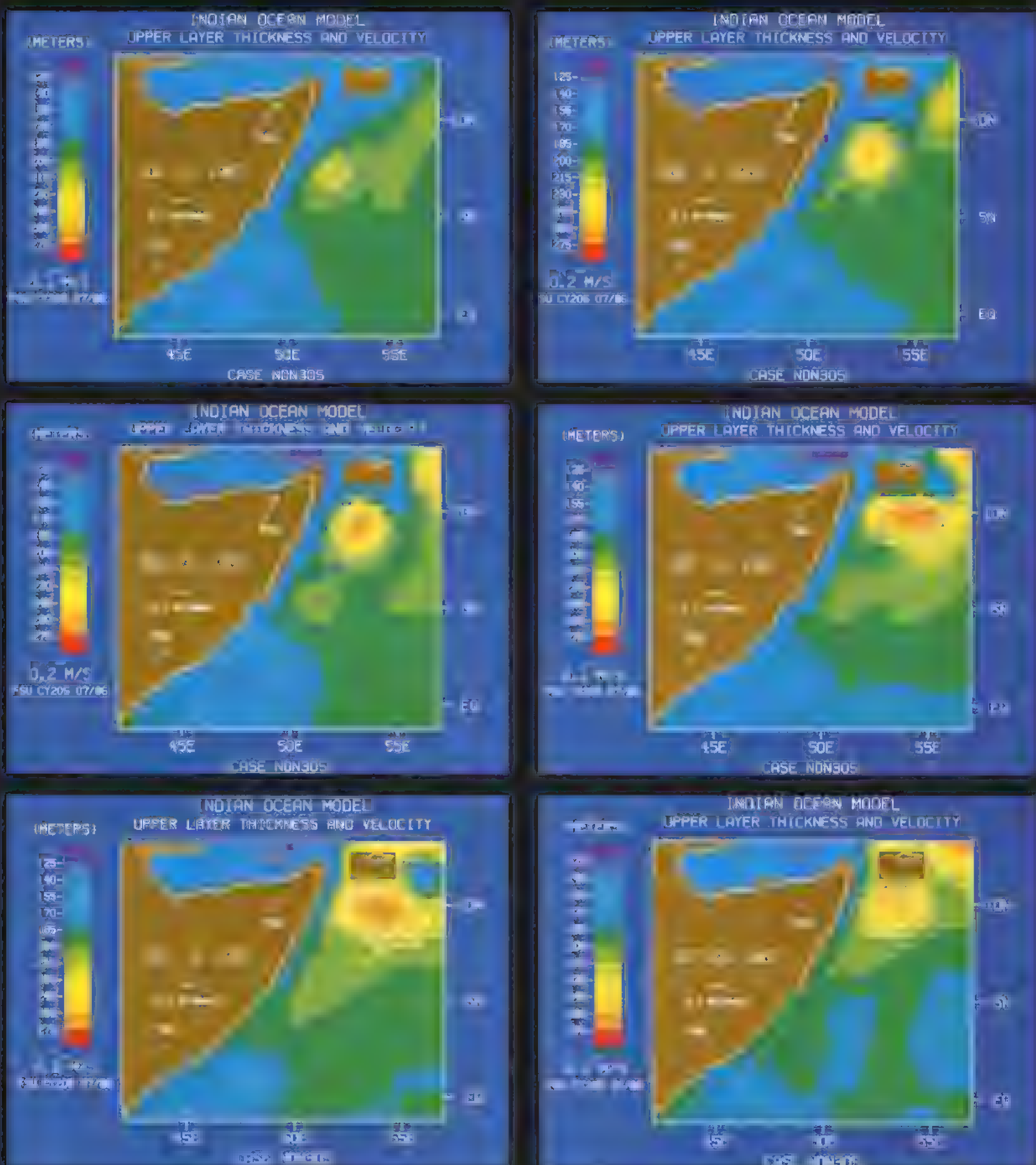
One major application of the system involves the computational modeling of fluid dynamical field flows in an ocean's surface layer. The thickness of the ocean's upper thermocline (the uppermost warm water layer on the ocean) is displayed by a color field, while a superimposed vector field represents the glow of a water current (as shown at right).

The Graphical Animation Software system requires a minimum of 12 bitplanes since it runs in double-buffered mode. Main memory should be at least 8 MB to facilitate the creation of graphical objects in memory (thus allowing for an increase in the display rate of frames). A second hard disk is also recommended, given that typical metacode display files can run 5-10 MB apiece, with larger files consuming as much as 30 MB. SGI's genlock option and a digital NTSC color encoder are required if a television or VCR are used for visualization and/or storage.

What is The IRIS Software Exchange?

The IRIS Software Exchange was created to make user-developed software accessible within the visual processing community on a non-commercial basis. Descriptions of the software are listed in a catalog compiled and published by SGI's User Services. The Exchange offers a number of nominally-priced tools and packages developed for or ported to SGI hardware. Silicon Graphics itself provides the source for selected demonstration programs and tools. For more information or to obtain a copy of the catalog, contact: Monica Schulze, Silicon Graphics, 2011 N. Shoreline Blvd., Mountain View, CA 90039-7311, (415) 962-3320 or <monica@sgi.com>.

Alan Davis is a computer research specialist in Florida State University's Department of Meteorology. For more information about the Graphical Animation Software system, contact Mr. Davis at (904) 644-3798 or <davis@masig1.fsu.edu>.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THE UNDERSEA WORLD OF INDUSTRIAL LIGHT & MAGIC

In little more than two months the computer graphics wizards in Lucasfilm's special effects facility created a thrilling submarine confrontation, without ever getting their feet wet.

BY CRISPIN LITTLEHALES

In the first underwater scene of Paramount Pictures' new release, *The Hunt For Red October*, the audience finds itself beneath the massive steel hull of a 600 foot long submarine moving swiftly through the dark infinity of the deep. The power of the submarine foreshadows the drama which later unfolds on this ominous undersea battleground.

As the film continues, we witness submarines chasing submarines; torpedoes tracking their targets; subs racing through a labyrinth of coral caves; and a final confrontation between three of these giant vessels which leaves us on the edge of our seats.

For most of the audience, the gripping special effects used to create these sequences are so subtle, that few are even aware of them. The result is believable, and that's exactly what Industrial Light & Magic, the special effects facility of Lucasfilm, Ltd., had in mind.

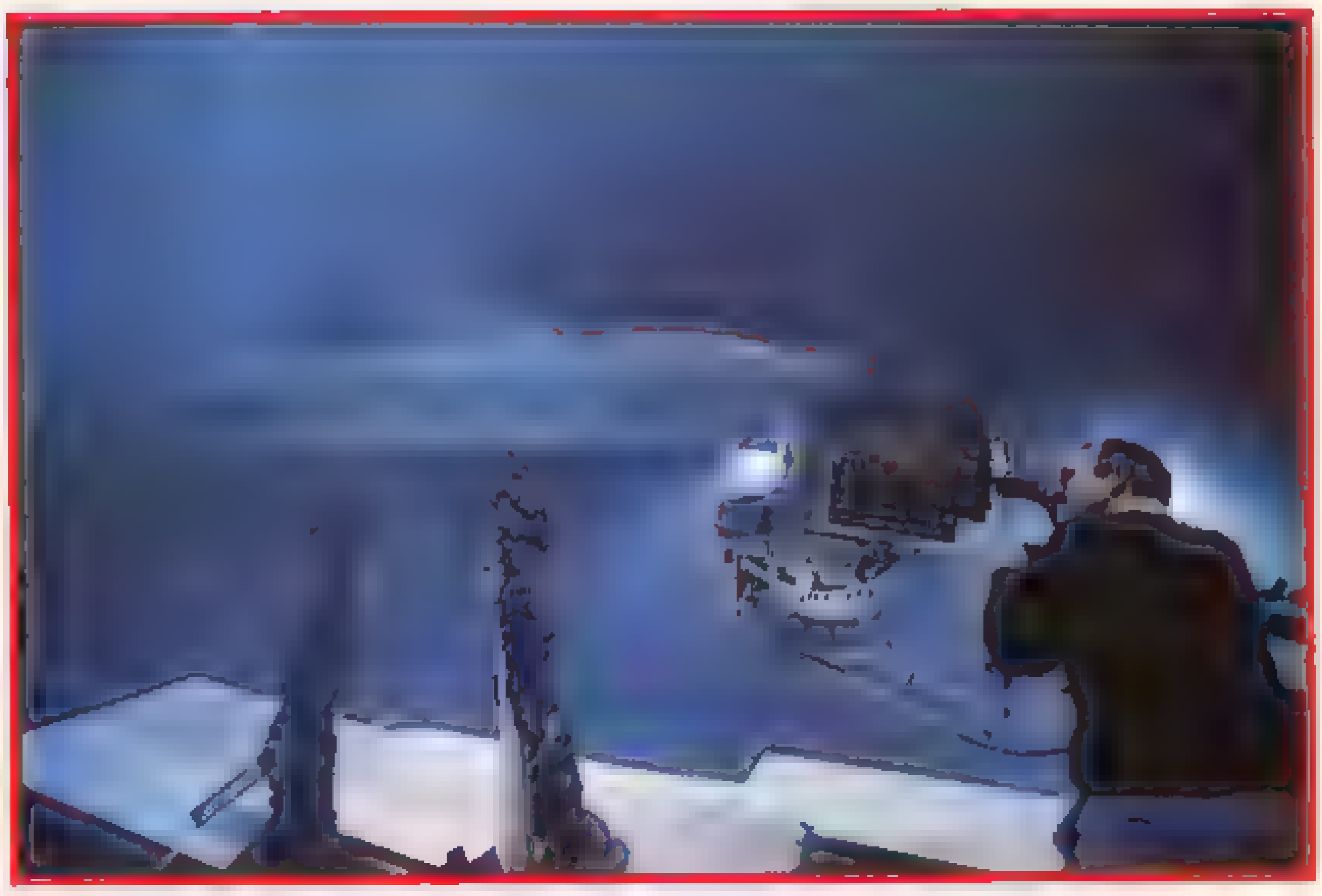
In truth, there were no huge subs, no torpedoes, no turbulence, no particles floating in the water, indeed, no water. The underwater sequences were filmed "dry for wet" with miniature models on a smoke-filled stage. These were then enhanced using a variety of techniques including very sophisticated computer graphics. The stage set-up established the overall drama of the shots, but the sense of reality and feeling of movement were heightened by the turbulence and particles created by ILM's Computer Graphics department.

From start to finish, ILM had less than six months to complete the project. In the world of special effects, that constitutes an unusually compressed schedule for such a large amount of work. ILM began the project by working from the script and storyboards. A rough cut of the film was also on hand.

The film's director, John McTiernan *(Die Hard)*, wanted to achieve a certain look for the undersea sequences which included giving the submarines an appearance of being propelled through water under power, thus the need for turbulence. He also wanted to make sure that the audience could understand movements of the camera and submarines. It was decided that this could be best achieved by introducing a frame of reference — particulate matter floating in the water. The approach conventionally used in special effects to simulate underwater was not, in itself, enough,

so ILM decided to enhance the stage work with a combination of computer graphics, animation, and optical compositing to achieve the desired look.

According to George Joblove, who supervised the computer graphics special effects for *The Hunt for Red October*, several key elements were used to provide the necessary visual signatures: turbulence or wakes trailing the submarines and torpedoes, and particulate matter floating in the water. Nearly all the computer graphics work for these effects, including most of the image processing, was produced using Silicon Graphics Power Series systems. In addition, a Silicon Graphics Personal Iris was used to write various software tools for creating and previewing the work.



Turbulence

Computer generated turbulence appears at the back of the submarines in three main shots. The first is the long establishing shot of the *Dallas*, the American sub. In-house, ILM refers to the shot as the "Star Wars" shot. The camera is stationary as the sub enters the frame from above and behind the viewers. As the propeller comes into frame, one can see a rippling effect surrounding it. (Here, some artistic license was invoked since water is actually incompressible). There are also two shots of the turbulence surrounding the *Red October's* caterpillar drive.

To create these images, Computer Graphics used the stage elements of the "underwater" background and the submarines. These were then manipulated — stretched and compressed in certain ways — then scanned back out to film. Steve Williams, one of several individuals working on the project, made numerical geometric models of the submarines. By putting key frames up on the Silicon Graphics system and using a double exposure technique between the actual film frame and the geometric model, Williams was able to match the movement of the live action submarines with the computer generated turbulence.

Particle Systems

In every undersea sequence in the film, there is particulate matter floating in the foreground. McTiernan felt that these particles contributed to the feeling of being under water. Computer Graphics used particle system techniques to generate eight or nine generic elements or patterns which were implemented by a camera moving through a field of particles in different directions at different speeds. These were first filmed individually as particles against black and then the optical department used the generic element best suited to the speed and direction of a specific shot.

The generic particulate elements worked well for most scenes, but there were several shots in which the camera was panning or changing direction. In such cases, Computer Graphics designed customized particulate matter based on motion control data which was taken from the cameras used to film the models. The computer generated elements were choreographed identically to the camera movement to look like a single element once the two had been composited.

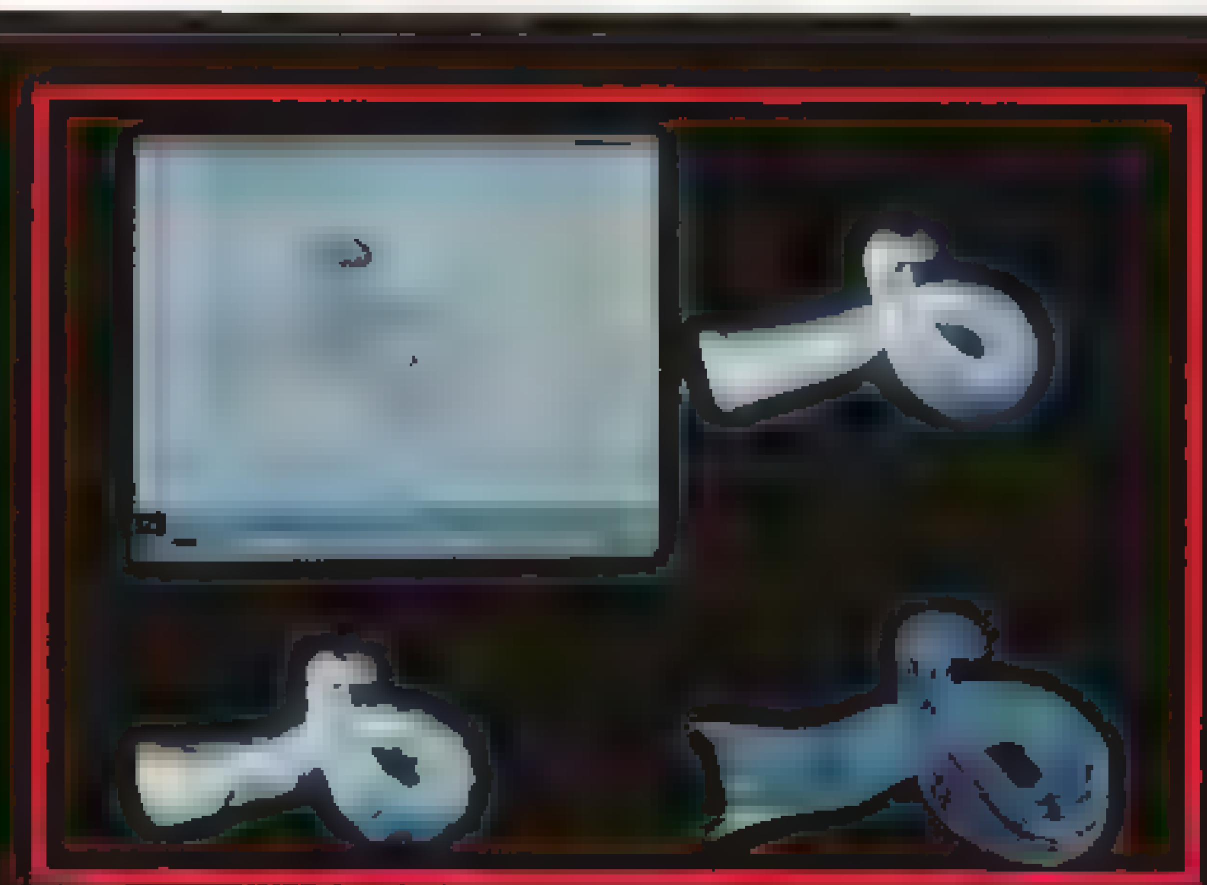
The use of particle systems in films is not unprecedented. ILM's first use of the system was in *Star Trek II* . It was used to create the effect of a "genesis bomb" which turned a

barren moon-like planet into a life supporting Earth-like planet. Particle systems have also been used in films to create star fields or explosions. Typically, the systems are used as a method of approaching a visual problem, and are, by nature, customized for each application. The particle system software used for the *The Hunt For Red October* was first developed by Scott Anderson, who joined ILM's Computer Graphics department two years ago. Anderson wrote the system on a Personal Iris.

Anderson's particle system program determined where the particles would be and placed the data in a file. That data could then be read by another program called a particle renderer, written by ILM's Mark Dippé. The renderer was used to create the images of the particles frame by frame.

Torpedo Wakes

The torpedo elements for the film were shot on the ILM stage against a blue screen background. The torpedoes'



ILM WINS ITS TENTH OSCAR FOR THE COMPUTER GENERATED "PSEUDOPOD" FEATURED IN *THE ABYSS*

At this year's Academy Awards, Industrial Light & Magic was presented with its tenth Oscar for best achievement in visual effects. ILM received the award for their work on *The Abyss*. Dennis Muren, visual effects supervisor on the project, accepted the statuette, his sixth Oscar for visual effects. Hoyt Yeatman of Dream Quest, Dennis Skotak of 4-Ward Productions, and John Bruno also received Oscars for their companies' contributions to *The Abyss*.

Muren supervised the creation of the "pseudopod," the strange creature made of seawater that enters the under-water drilling rig and comes face-to-face with the film's stars, Mary Elizabeth Mastrantonio and Ed Harris.

Many visual effects and computer graphics experts consider the pseudopod effect to be significant because it is the first time an organic creature has been successfully modeled and animated using computer graphics, and realistically composited into live action for a feature film.

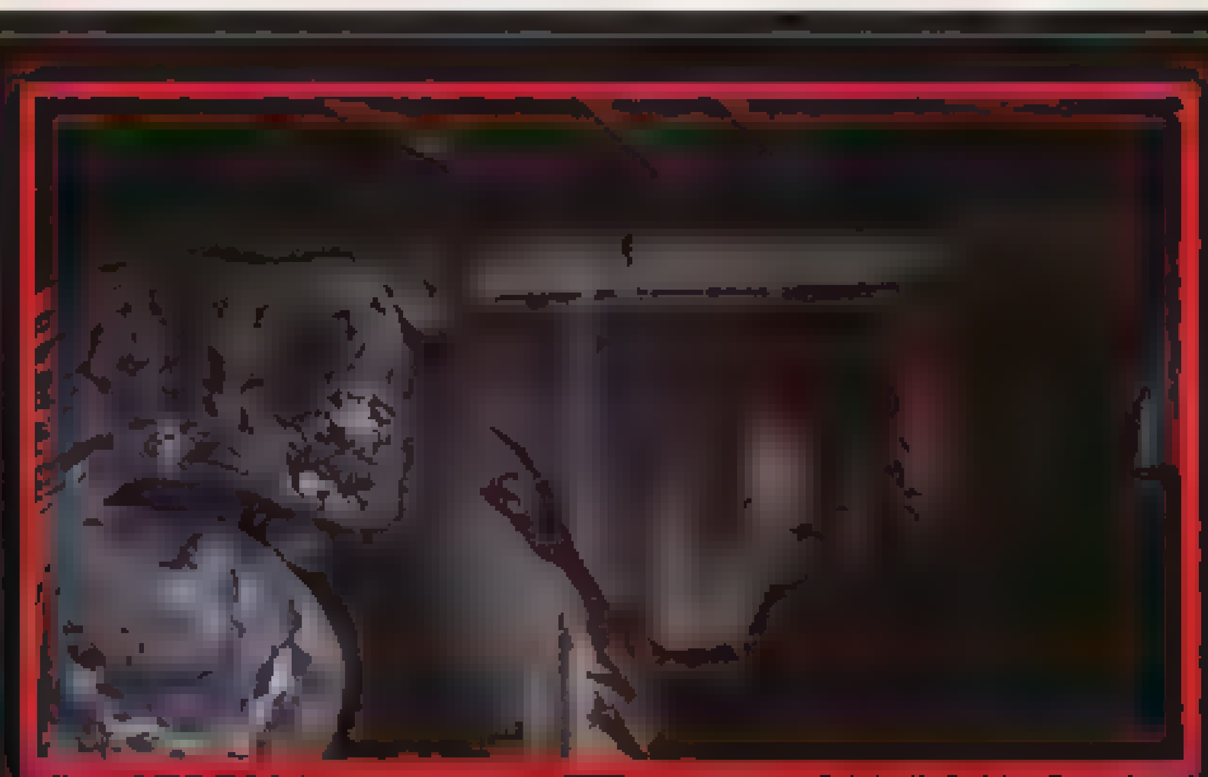
The modeling was done using the Alias/2 software package along with ILM's proprietary pseudopod software on Silicon Graphics' 4D/70 GT and 4D/80 GT workstations.

The animated models were combined with environment texture maps created from photographs taken on the film set, and then rendered on four SGI 4D/120 multiprocessor systems using Renderman. The creature's "skin of water" texture was created using ILM's specially written software to "bump" the surface of the pseudopod, then timing and animating the bumps to react and look like water. Since much of the character of water comes from light and the reflections it carries, the computer was programmed to measure the precise angle of every surface in every frame.

In the scene where the pod reconfigures its face to mimic the actors, ILM's Computer Graphics team used a three-dimensional digitizer, basically a laser scanner,

fiery looking wakes were generated using particle system techniques; in this case, computer generated bubbles. Those elements were then delivered to ILM's Optical Department for final compositing with the torpedoes and the background plates.

In addition to Turbulence, Particle Systems, and Torpedo Wake effects, Computer Graphics did some touching up here and there. On two of the shots Computer Graphics actually scanned in the whole frame, then manipulated the image and scanned it back out. The wires that were



Courtesy Industrial Light & Magic

which made a separate scan of the actors' expressions. The raw data was then fed into the computer graphics system and manipulated electronically. Only the key expressions were digitized, with the computer interpolating or filling in the in-between frames, utilizing a "morph" program developed for use on *Willow*.

In its February 1990 issue, the highly regarded *American Cinematographer* magazine said that the pseudopod effect "ILM created last summer for *The Abyss* proved... spectacularly [that] synthetic imagery really works! That effect will probably come to be regarded as the turning point in film history when computer generated imagery went from being a freak technique to being respected as a serious tool."

"The exciting thing is that we discovered we can get computer graphics to do things that were once thought to be impossible," said project designer John Knoll. "Now almost anything can be modelled and brought to life."

Silicon Graphics congratulates all the contributors to the visual effects used in *The Abyss* for their innovative work.

used to move the models still remained in view. These were removed with a program originally written by Doug Smythe for work on *Back To The Future II*. In one shot, part of the stage floor appeared in the frame and Smythe wrote a variation of the "wire removal" program, now referred to as the "floor removal" system.

ILM had about six weeks to do all its research and development, define the effects' "look," and handle all the necessary software development. Once the shooting was underway, and the project progressed, ILM continued to test and refine its final output. In addition to overcoming technical hurdles, Computer Graphics worked closely with the film's director, McTiernan, as well as Scott Squires, the visual effects supervisor, and John Knoll, who served as associate effects supervisor, to achieve the appropriate look and feel. Feedback was provided on a daily basis by both Squires and Knoll. The department functioned with two shifts, running all the image processing overnight on SGI's Power Series machines.

One of the most challenging things about the

assignment, according to George Joblove, was completing so much work on such a tight schedule, since there was virtually no time for mistakes. What seems to have satisfied Joblove most about the project is ILM's success in making the computer generated special effects integrate seamlessly with *The Hunt for Red October's* live action sequences, so that the audience is convinced they're viewing "600 foot long subs moving under water and not 22 foot long plastic models in a smoke filled room."

Crispin Littlehales is a freelance writer in San Francisco, California.

Silicon Graphics Systems in Use at ILM

The SGI equipment listed here is currently installed in the Computer Graphics department at Lucasfilm's Industrial Light & Magic.

- 3 – 4D/240GTX Graphics Workstations each with 64MB memory.
- 1 – Graphics 4D/240 Server with 64MB memory.
- 3 – 4D/25G Graphics Workstations each with 16MB memory.
- 1 – 4D/80GT Graphics Workstation with 16MB memory.
- 1 – Silicon Graphics 4D/70GT Graphics Workstation with 16MB memory.

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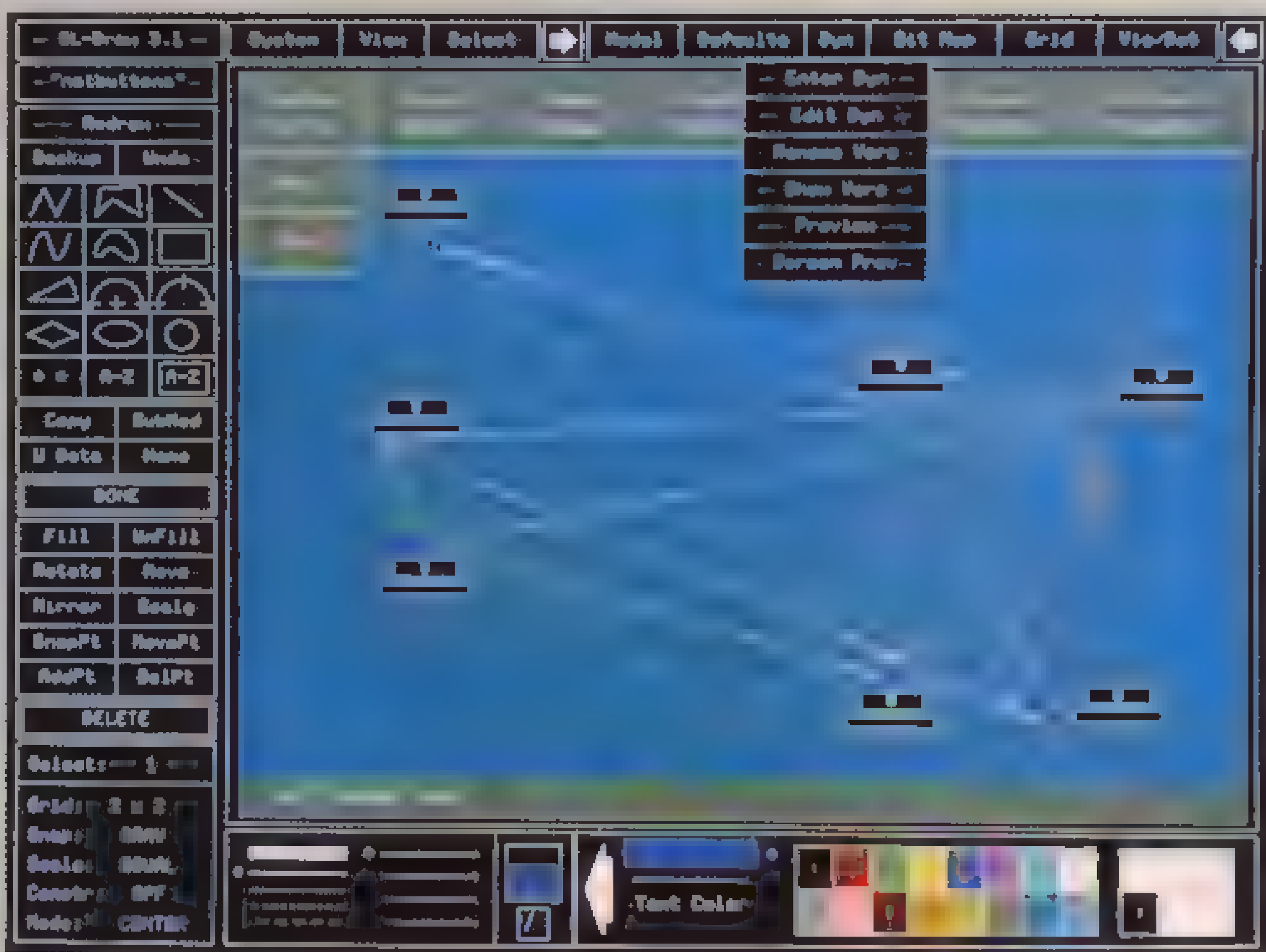

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- A superior object-oriented architecture.
- A more powerful drawing tool.
- Direct, table-driven access to application data variables.
- More than 40 dynamic actions for graphic objects.
- Easier creation of custom graph types.
- Generally, a more open and extensible system.

A Graphics Tool that Adapts to You—Not the Other Way Around.

SL-GMS provides users with a uniquely open and extensible development system. SL Corporation believes a graphics tool should allow developers to create screens that look the way the developer wants them to look, not the way the toolmaker requires them to look. With other tools, developers wishing to go beyond vendor-supplied graphic objects and behaviors are forced to resort to raw coding. In contrast, SL-GMS not only supplies over 40 basic graph types and 40 dynamic actions, but also provides a rich set of "building blocks" that the developer can use for modifications and extensions. All SL-GMS functions can be accessed by calls to the SL-GMS function library, providing developers with additional design flexibility.

A More Powerful Drawing Tool.

Anyone can use the SL-DRAW graphics editor, a mouse-driven environment that is a powerful extension of standard drawing programs. With the point-and-click interface, users can easily create a wide variety of graphic objects and position them on the screen.

SL-DRAW allows the specification of all standard graphic attributes including color, line width, fill percent, size, rotation, position, and text font. In addition, SL-DRAW supports many CAD-like editing operations not usually found in graphics packages, including a variable-spaced grid, backup and undo functions, point congruence, snap-to-grid, pan and zoom utilities, and the ability to add to, delete from, and move the points of an object. Any graphical attribute which can be specified from SL-DRAW can be dynamically modified in response to changes in external data.

SL-DRAW derives much of its power from the object-oriented architecture of SL-GMS. The SL-GMS user can create a screen with many objects just by creating a single object (such as a meter) and "instancing" it. Dynamics can be applied to the "generic" object and/or to the instances themselves. For example, some attributes can be attached to all instances of the object at once, while a different property or dynamic behavior can be specified for each instance. The result of this hierarchical, object-oriented approach is an increase in developer productivity that cannot be matched by "flat" systems.

Output Dynamics

The dynamics functions used to animate screen objects can be specified from the SL-DRAW editor. These functions establish direct connections between screen elements and application database variables. Screen objects and object components—even sub-component elements and text—can be animated to reflect real-time changes in application variables.

Direct Access to Application Data

The advanced architecture of SL-GMS makes it possible to control animation and dynamics through a simple table-driven approach which links data variables to screen elements.

Input Dynamics

Screen objects created with SL-GMS can also be used by the end-user to interact with the application. SL-GMS "GISMOS" can perform actions, evaluate expressions, reference variables and call user-defined functions, as well as input data values and switch between screen states.

Text Editor Option

The SL-GML Language interpreter is a full-command alternative/complement for editing screens in text mode. It handles conversion of binary-screens to ASCII or C-structure files for portability across platforms or compilation into diskless runtimes. It can make de-bug format dumps of screen files. SL-GMS simplifies the layout of complex screens which involve multiple, tiled, or overlapping views.

Advanced Technology

The design of SL-GMS is founded on the SL-Object Oriented Environment (SL-OOE)—a tested, stable and pioneering implementation written in straight C. This kernel environment is complete, simple and elegant, and requires no special compilers, pre-compilers or C-language extensions, even though users wishing to integrate with C++ or Objective C may do so.

Designed Portability Protects Your Investment

Screens and programs built with SL-GMS on any supported platform run automatically on any other supported platform. This allows users to build screens on lower-priced, lower-performance hardware, and then run them on faster, more capable hardware . . . or the other way around. Screens you have developed will remain transparently functional despite technical change, because SL-GMS is truly device-independent.

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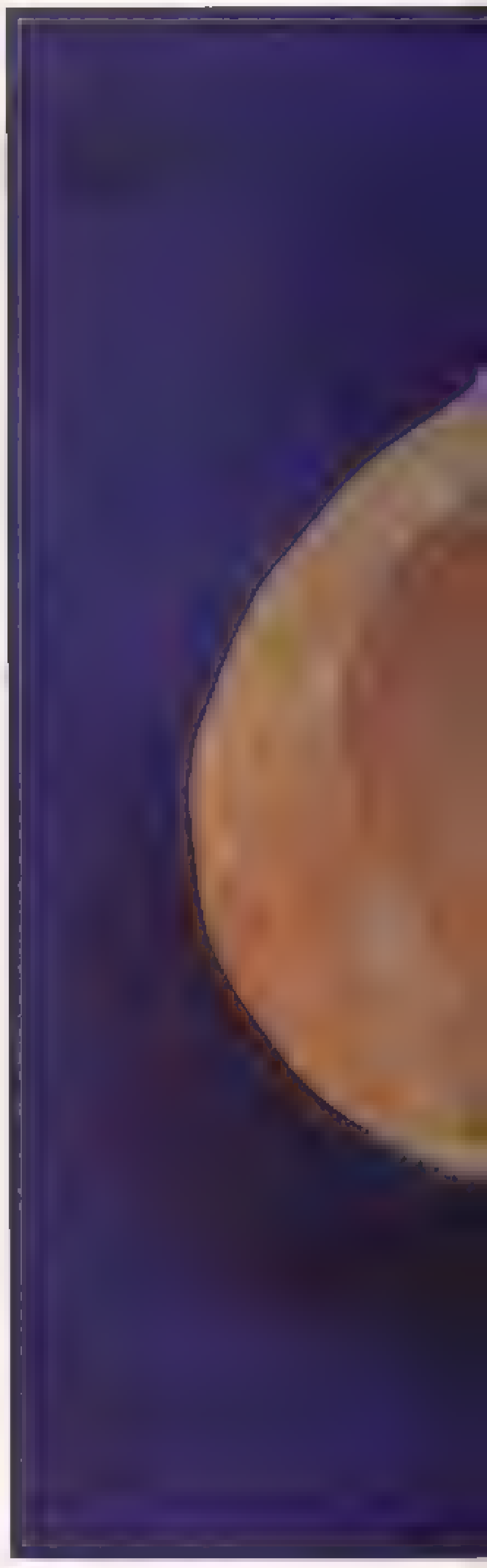


Through a new process called stereolithography, artists and engineers can create full three-dimensional models in plastic from computer data.

BY STEWART DICKSON

At the 1990 SIGGRAPH in Dallas, there may be an exhibition of sculptures which really shouldn't exist. Created using "stereolithography," a new process for printing full three-dimensional models from computer data, sculptures of near-impossible forms will be fabricated with information sent from a CAD workstation. Employing a laser-based 3D rapid prototyping tool and photosensitive acrylic, close approximations of theoretical solids which can be topographically described by mathematicians, but which cannot actually exist in the ordinary physical world, can be fabricated in a matter of hours.

I first heard of stereolithography through my work as the programmer of three-dimensionally-modeled computer graphics and animation at The Post Group in Hollywood, California. Stereolithography, was developed by 3D Systems in Valencia, California. The process is based on a liquid polymer resin which hardens under the influence of a computer-controlled laser. Very much like a 3D laser printer, an elevated platform submerged in the liquid accomplishes a layer-by-layer building up of a form through a series of electronic cross-sections, or slices, of a 3D CAD model. Early adopters of the technology include General Motors, Baxter Health Care, Eastman Kodak, Pratt & Whitney, and Apple Computer, where mechanical engineers used a Stereolithography Apparatus (SLA) to produce prototypes of computer parts such as fan blades.

A stereolithograph of Steward Dickson's Knot (the Torus Homeomorphic to the Trefoil Knot), as output in polymer-resin by 3D Systems of Valencia, California.

The basic components of 3D Systems' SLA consist of a UNIX engine that runs the company's proprietary slicing software, Ethernet networking, a DOS-based microcomputer running control software, a mirror x-y scanner, a laser and an elevator mechanism that moves up and down within a vat containing an ultraviolet-sensitive liquid polymer called DeSolite. For the UNIX portion of the setup, 3D Systems makes available either a Silicon Graphics Personal IRIS workstation or 80386-based NEC workstation.

I had a particular interest in stereolithography because of my long-standing involvement with sculpture, particularly non-representational sculpture that embodies mathematical concepts. With stereolithography, I saw a chance to create works of art based on new mathematical research of impossible — but appealing — forms.

Mathematicians know of a class of surfaces that mimics film drawn from wire curves dipped in a soap solution. Called "minimal surfaces," there are few examples of equations having the requisite properties — finite total curvature (energy- and surface-area minimizing property) and embeddedness (non-self-intersection) in three-space. The history of the study of these special properties dates back to J. L. Lagrange in 1760, with most of the examples known today discovered between 1760 and 1865.

In 1983, Celsoe Costa, a graduate student in Rio de Janeiro, Brazil, wrote down the equations for a new example. The equations were so complex that the geometry of the object was obscured. Also, Costa was unable to prove that the surface was embedded.

In 1984, Professors of Mathematics David Hoffman and William Meek III teamed up with computer programmer James T. Hoffman at the University of Massachusetts, Amherst. Together they were able to redirect their mathematical arguments and successfully prove the embeddedness of Costa's Surface. They did so by rendering pictures of polygon approximations of the equation for the surface. In the process, Hoffman, Meeks, and Hoffman were able to find the symmetries in the surfaces. These symmetries suggested that Costa's Surface was only one of an infinitely large class of related surfaces. These surfaces are single-sided

A stereolithograph of Dickson's* Genus 1, Four-Ended Minimal Surface of Hoffman and Meeks, Containing a Topological Handle. *Output by 3D Systems, Valencia, California.

and have no thickness — "impossible soap bubbles." Theoretically acceptable, they are not physically realizable.

Both their forms and the way they were derived are profoundly beautiful. Discovering a new class of surfaces with special properties by using computer modeling methods is a radical departure from traditional mathematics. There, mathematicians have relied on drawing and occasionally on the skills of craftspeople to illustrate and provide an intuitive explanation of a theory. Yet a link has always existed between art and math. Fractals pioneer Benoit Mandelbroit found that the feedback obtained from computer-generated images of his equations dramatically changed the nature of his study. The study of minimal surfaces as sculpture is akin to the distillation of form to its essential purity as practiced by the Italian sculptor Constantin Brancusi.

But are the objects that have been discovered through computer graphics art or mathematics? David Hoffman has called a recent traveling exhibition of photographs of the minimal surfaces "an exhibition of mathematics." Scientists Heinz-Otto Pietgen and Peter Richter term their photographic exhibitions of Mandelbroit and Julia sets MapArt (Julia sets are complementary mappings of Mandelbroit functions). Similarly, a few artists such as Ruth Vollmer, Max Bill, and Mauritus C. Escher adapted what they saw in mathematics to artwork they subsequently called their own.

To create physical models of these mathematically significant and aesthetically satisfying forms, I proposed making sculptures of minimal surface forms using the new SLA technology. The mathematical models had to be "thickened" through data manipulation programs in order to be turned into 3D art objects, a process that James Hoffman verified would create faithful renditions of the original surfaces. The surfaces of the object are involuted in a way that makes them impossible to machine and extremely challenging to cast.

On the technical level, a two-fold conversion process first involved the adaptation of the minimal surface objects received from James Hoffman. The binary geometrical patterns of the objects described in Hoffman's Visual Programming Language had to be mapped out in a format the SLA could work with. The second tier of the conversion referred to the topological connectivity of the objects: the surfaces must be closed and homogeneously connected. A homogeneous right-hand connectivity of the polygon net (all polygons oriented counter-clockwise) is a requisite to being able to tell whether the surface is closed. Each edge shares exactly two polygons and each vertex shares the same number of edges as polygons.

The Wavefront Technologies' 3D graphics animation software used to make the sculptures had two limitations. First, Wavefront's software was unable to render polygons which were



Left to right: The rendered images of the Manifold Torus of Tetrahedral Geometry/Topology, The Klein Bottle, *and* Photosculpture *— a luminance contour graph or map of a digitally captured video image converted into a geometrical object. ©Stewart Dickson, courtesy of The Post Group.*

facing away from a camera and had no way to tell if a surface was homogeneous or closed. What's more, James Hoffman's objects were single-sided, equipped with rendering programs that treated the backs of polygons the same as the fronts. This is acceptable in theory but useless in the creation of sculpture, which cannot be infinitesimally thin.

In sum, conversion programs had to be written to transfer object data between Wavefront Technologies and SLA object description conventions. Software had to be created that tested for the closure (the condition of everything being connected) and for homogeneous connectivity of a surface (everything being connected in the same direction). Finally, software had to be developed to produce closed surfaces of finite thickness, suitable for stereolithography, with verification of manifold connectivity (where certain kinds of multiple connections are prohibited, so that, for example, more than two polygons can't share the same edge). Nora Lesnet, 3D Systems' Senior Software Support Engineer, helped test the output and certified the Wavefront-3D Systems conversion programs. Wavefront has since listed the programs as third-party products available to Wavefront users.

The rendered image of Dickson's Knot *(The Torus Homeomorphic to the Trefoil Knot). A photograph of the form as output in acrylic appears on pages 24 and 25. ©Stewart Dickson, courtesy of The Post Group.*

The object data-conversion programs operate on all Post Group workstations connected to our 3D computer network. The network at our newly-opened Hollywood Digital Center is made up of a Silicon Graphics IRIS 2400GT, IRIS 3130 graphics workstations, an IRIS 4D/60T computer Server (CS-12), and a Sun Microsystems 3/160 workstation.

Ken Sims, Silicon Graphics' Los Angeles sales representative, kindly lent me a 4D/20 Personal IRIS to use at home to create the pictures of the sculptures proposed for SIGGRAPH 90. Don Brittain, Director of

The rendered image of the Genus 1, Four-Ended Minimal Surface of Hoffman and Meeks, containing a topological handle. *A photograph of the form as output in acrylic appears on page 26. ©Stewart Dickson, courtesy of The Post Group.*

Research at Wavefront Technologies, gave me a six-month loan of the company's Advanced Visualizer software, Gorson Padwick, 3D Systems' Director of Marketing Communications, took charge of rendering the first stereolithograph.

A Genus 4, three-ended minimal surface was manufactured at 3D Systems on January 5, 1990. The form had been postulated to exist more than 100 years ago, but had remained unproven until then. It now existed for the first time outside the interior of a computer, a physical form accurate within one-hundredth of an inch of its theoretical shape. Its surface properties are those of a soap film drawn from a wire edge.

At present the sculptures are limited in size by the SLA's current

The rendered image of the Helicoid. *©Stewart Dickson, courtesy of The Post Group.*

maximum manufacturing capacity — roughly the size of a 10-inch cube. Some of the pieces intended for SIGGRAPH '90 put into material form the minimal surface research performed by James Hoffman and William Meeks. Others create near-replicas of 100-year old impossible forms, such as the helicoid and the catenoid.

Stereolithography gives us the unique opportunity to transmigrate forms which have evolved in an abstract numerical vacuum and allow them to have substance for the first time. It is now possible to put into extremely accurate physical form a machine-resident image of a human thought process.

Stewart Dickson is a programmer working in three-dimensionally-modeled computer graphics and animation at The Post Group, a full-service video editing, post-production, and special effects facility located in Hollywood, California.

THE ART OF THERMODYNAMICS

Motivated by the century-old work of an unsalaried professor at Yale, two modern day chemical engineers are illustrating thermodynamic ideas with spatial models created on an IRIS workstation.

BY KENNETH R. JOLLS
AND DANIEL C. COY

One of the principal objects of theoretical research in any department of knowledge is to find the point of view from which the subject appears in its greatest simplicity.

— J. Willard Gibbs

Among the sciences, no single discipline is as dreaded, maligned, and misinterpreted as thermodynamics. Despite its irrevocable involvement in all the processes of nature, it is shunned by the novice, mistrusted by the professional, and ignored by the layperson who, in blissful ignorance, may ask more from nature than thermodynamics tells us nature is willing to give. For over a century it has been the nemesis and undoing of countless thousands of students who have stumbled over its postulated logic and subtle truths, often finding it illogical and contrived.

Yet few subjects have inspired so many. Modern thermodynamics has been shaped by great minds dating back to the middle of the eighteenth century. But in the years since 1870, one person above all has emerged as synonymous with the rigorous formalism of the "queen of the sciences" — Josiah Willard Gibbs.

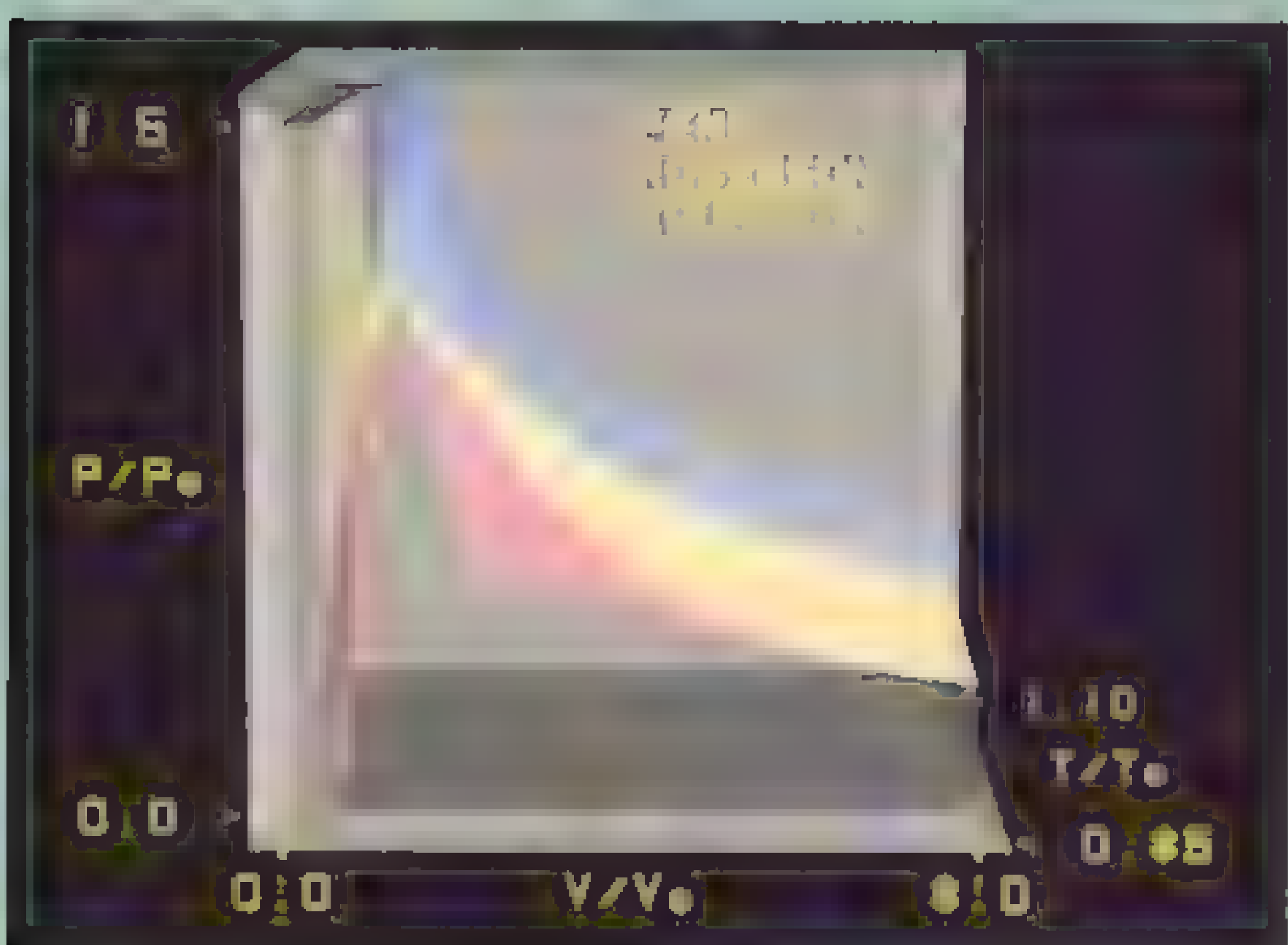
In the spring of 1873 Gibbs published the first part of his great trilogy on the mechanics of heat, "Graphical Methods in the Thermodynamics of Fluids." The first sentence of that paper provided the motivation for the research reported here 117 years later: "Although geometrical representations of propositions in the thermodynamics of fluids are in general use and have done good service in disseminating clear notions in this science, yet they have by no means received the extension in respect to variety and generality of which they are capable."

Though not the first to express thermodynamic ideas through spatial models, Gibbs extracted more from the geometry than did his predecessors. From the contours of these models he developed rationales for the state of a system (solid, liquid, gas) and for the tendency (through consideration of thermodynamic stability) for such states to change. For the first time a geometric art form was proposed to show the structure and logic of thermodynamics rather than to portray properties in some suitable coordinate system.

But Gibbs' papers themselves contained very little graphic geometry. The analogies were cast in words, not drawn in pictures. And for those who could not follow the elaborate verbal manipulation of lines and planes in space that permeates his writings, the physical meaning and the artistic beauty of these brilliant analogies were lost. Indeed the interesting connections between thermodynamics and geometry, which were the essence of Gibbs' theoretical development, have all but vanished from the literature. That this was inevitable is not hard to understand. The difficult conceptual and artistic task of transforming Gibbs' ideas into

The Equation of State (PVT)

Unstable region included.



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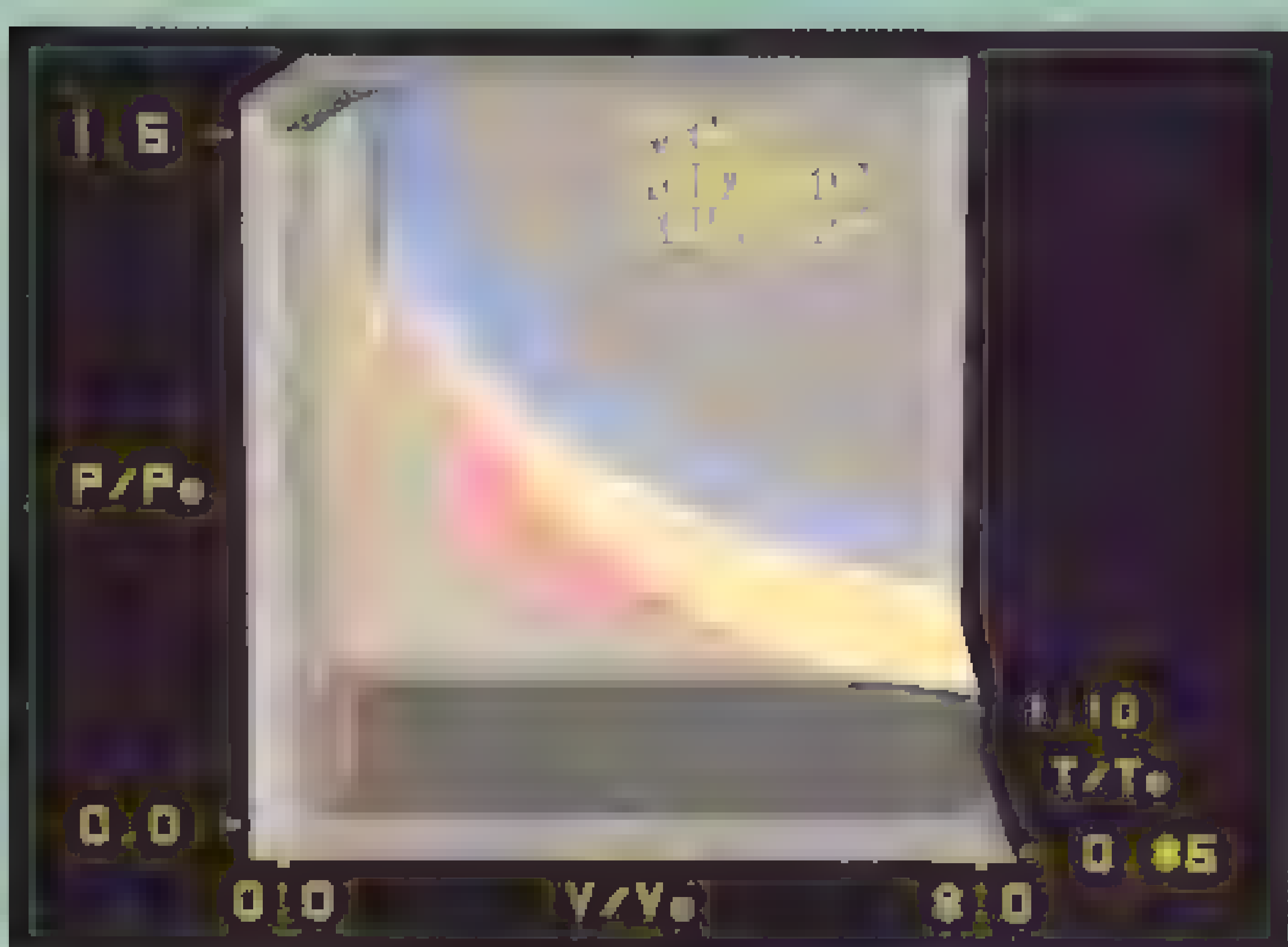
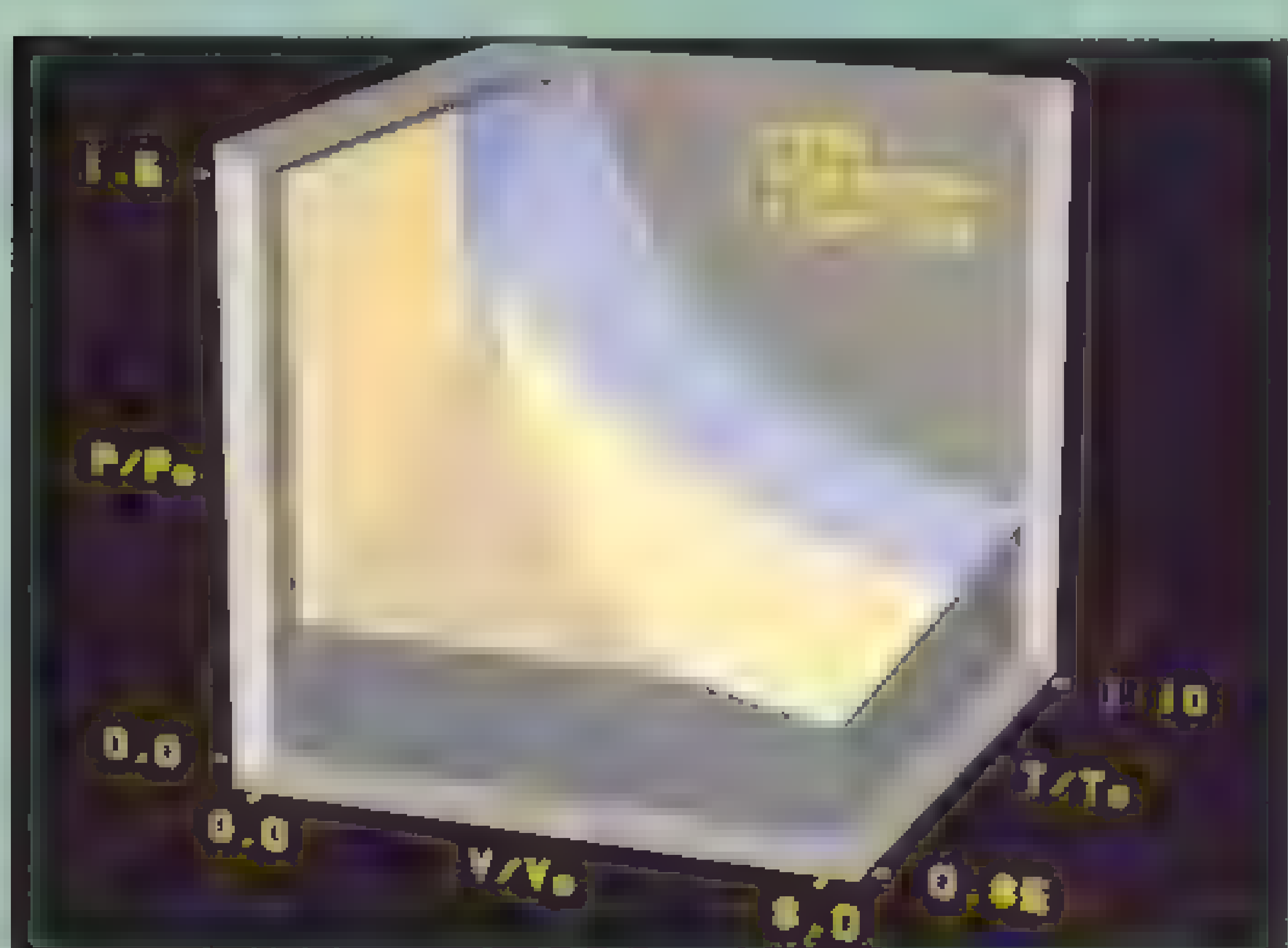


Metastable branches attached, coexistence surface transparent.



Metastable branches removed, coexistence surface opaque.

three-dimensional models and drawings of such models has been attempted by only a few.

Until fairly recently, visualizing geometrical analogies of complex physical phenomena has not held a high priority in science. And, until the introduction of superior modeling platforms with high performance graphics, the visualization process itself has been difficult, expensive, or impossible.

There can be no doubt in the mind of any serious thermodynamicist that the images accompanying this article were vividly in Gibbs' mind as he wrote his famous trilogy in the mid 1870s. Our role has been to do the mechanics of those visualizations and produce images that were unproduceable at that time.

In this article we show the surfaces corresponding to the four "fundamental" equations for a pure fluid. These natural groupings of thermodynamic variables are listed below along with their modern symbols. The dimensions of the four dependent quantities (U, A, H, G) are energy/mass while those of the entropy (S) are energy/mass · temperature. All variables have been nondimensionalized for plotting.[1]

Dependent Variable	Independent Variables	Complete Set
energy (U)	entropy, volume	USV
Helmholtz energy (A)	temperature, volume	ATV
enthalpy (H)	entropy, pressure	HSP
Gibbs energy (G)	temperature, pressure	GTP

The parent structure among these (and the foundation of the Gibbsian approach) is the energy-entropy-volume or USV model. This structure is labeled as the "Gibbs surface" in Figures 5-8 and was deduced from a geometrization of the combined First and Second laws of Thermodynamics through the differential equation

$$dU = T\,(S,V)dS - P\,(S,V)\,dV$$

where the variables are defined as in the groupings above. The USV function encodes the totality of thermodynamic information about a system and makes that information accessible for recall (usually) through partial differentiation. The familiar quantities, temperature, and pressure exemplify this.

$$T = \left(\frac{\partial U}{\partial S}\right)_V \qquad P = -\left(\frac{\partial U}{\partial V}\right)_S$$

Gibbs derived the Helmholtz energy, enthalpy, and Gibbs energy forms from the USV function as follows:

$$A = U - TS \qquad H = U + PV \qquad G = U - TS + PV$$

Today we recognize these relationships as Legendre transformations — geometry-based shifts in one or both of the independent variables of a given form. Enthalpy, for example, is a first transform of the USV function where the volume variable has been replaced by the pressure.

The nature of the Legendre transform preserves thermodynamic information among the shifted variable sets and functions so as to make certain dependencies more accessible in one coordinate system than in another. As already noted, temperature and pressure appear as slopes on the Gibbs surface, but in the other systems they constitute one or both coordinates. Geometric manipulations specific to each system model the practical operations of classical thermodynamics, and we designate each of the variable sets as equivalently fundamental.

The "defined" character of the energy and entropy functions precludes their direct measurement. In the context of the images shown here, their determination is based on certain measurable thermodynamic derivative functions (compressibilities, expansion coefficients, heat capacities) that may be combined and integrated to obtain the parent fundamental forms. The specific approach used in this study was to combine a common pressure-volume-temperature (PVT) relationship with an expression for low-pressure, constant-volume heat capacity (C_v^*) and perform the integrations and other operations needed to produce the appropriate generating equations.

The PVT relation upon which this work is based is the well-known Peng-Robinson equation,[2] and the surface generated by that equation (with successive modifications dictated by stability theory) is the subject of figures 1 through 4.

The remaining groups of figures represent the first coherent set of thermodynamic fundamental equation surfaces constructed in the history of the Gibbsian formulation. Prior attempts to characterize the individual structures by hand have largely been ineffective because of the need for graphic accuracy to the level of the second derivative.

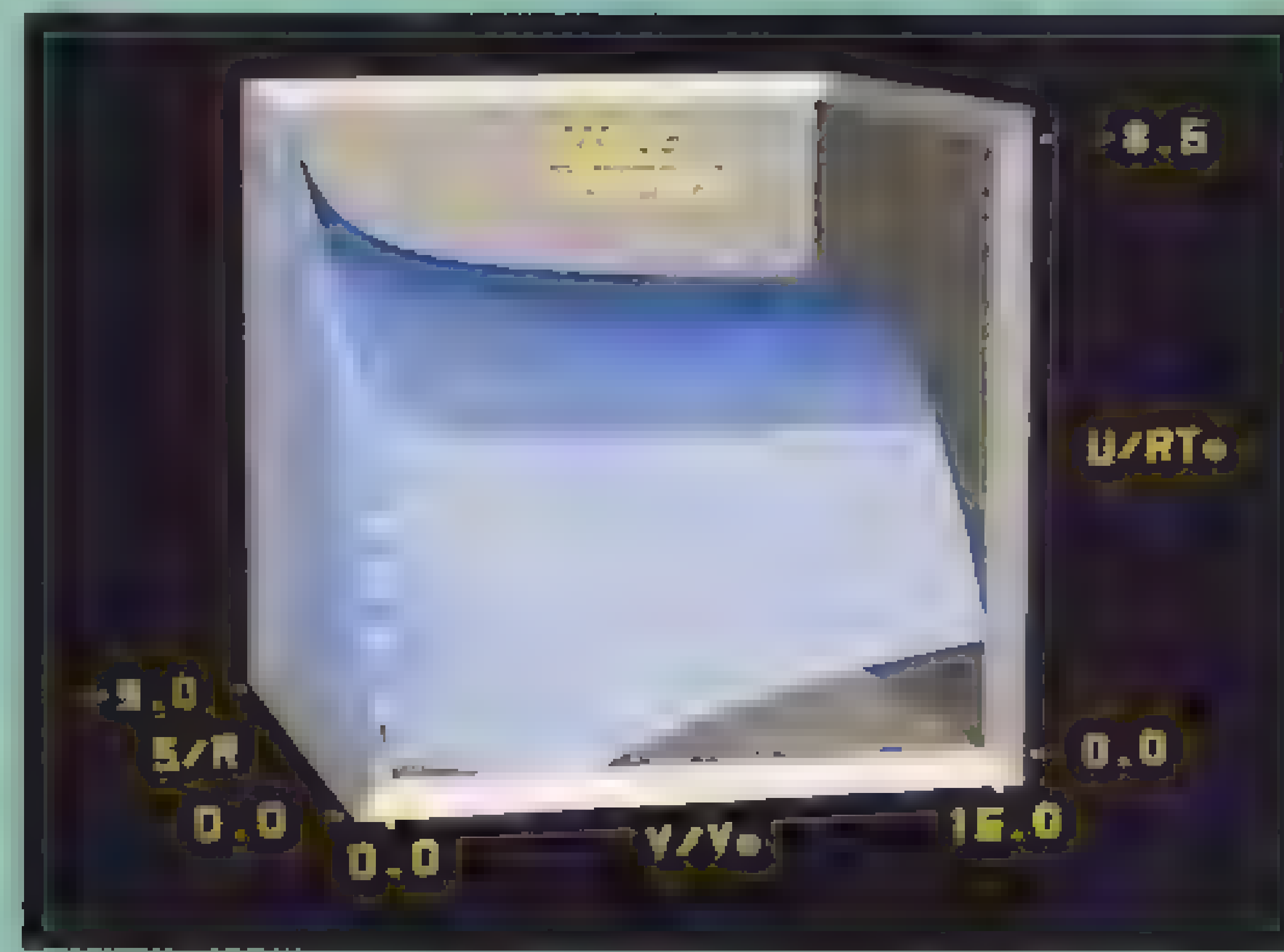
For each of the five sets of images the complete phase surfaces were partitioned according to stability theory and the node coordinates computed relative to that sectioning. For graphics processing, the sectors thus defined constituted "parts" that could be assigned independent attributes. This enabled the color scheme, for example, to denote local stability rather than requiring the observer to infer that

Definitions

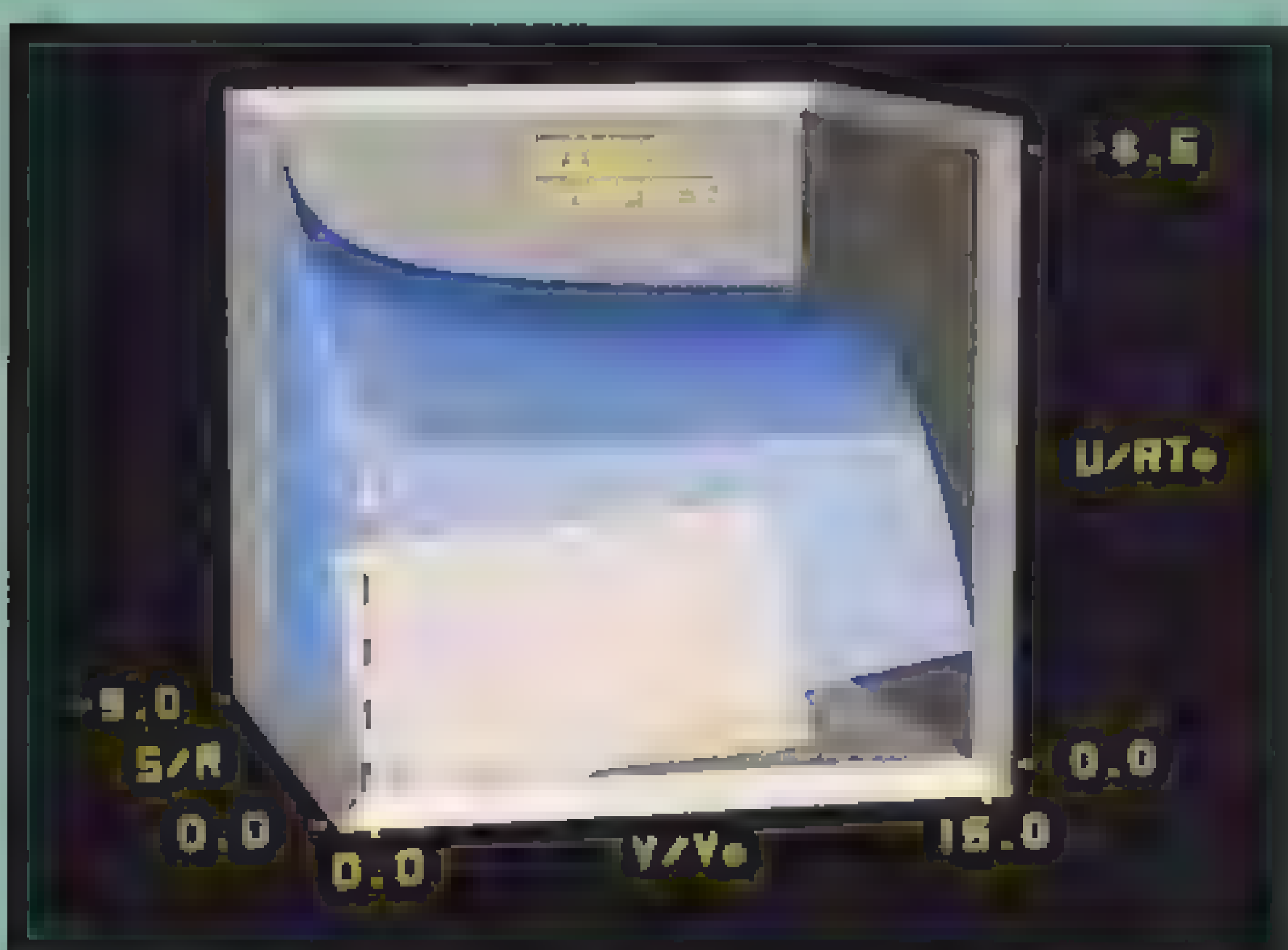
isotherms (isobars)	Lines or curves along which the temperature (pressure) is constant.
critical point	The point at which the properties of the coexisting vapor and liquid phases become indistinguishable. Temperatures above that of the critical point are called supercritical — those below are termed subcritical. In all but the three final USV images, supercritical states alone are colored blue.
stable	Thermodynamic conditions under which a substance can exist indefinitely. Stable states are shown in yellow (light tan).
metastable	Conditions under which prolonged existence is possible only with special experimental procedures (shown in orange)
unstable	Conditions under which existence is forbidden by the Second Law of Thermodynamics (shown in light brown).
coexistence	The simultaneous existence of separate phases in equilibrium (e.g., liquid and vapor). Straight lines connect coexisting states in the USV, ATV, HSP, and PVT coordinate systems. The composite of all such lines in a given system is called a coexistence "surface" (colored green in the ATV and HSP images, olive in PVT).
vapor region	Subcritical states at high values of V/V_c or low values of P/P_c.
U_{SS}, U_{SV}	Shorthand notation for second-order partial derivatives: $\left(\frac{\partial^2 U}{\partial S^2}\right)$, $\left(\frac{\partial^2 U}{\partial S \partial V}\right)$, etc.

Energy-Entropy-Volume (USV)

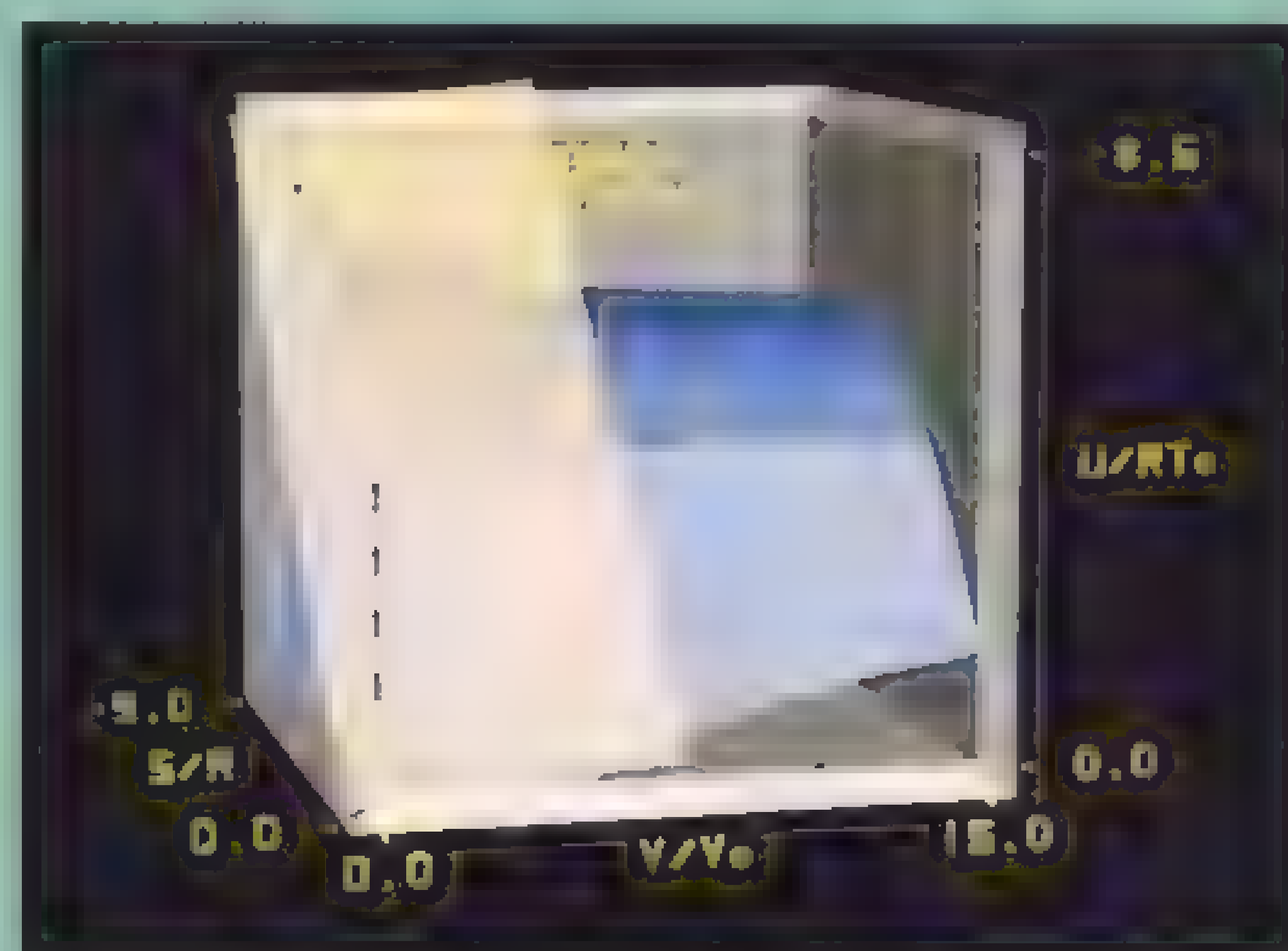
This image follows the color code. The critical point is at the junction of the six colored zones. The unstable region violates the stability criterion $U_{SS}U_{VV} - (U_{SV})^2 > 0$. Energy is positive downward.



In this image all stable states are light blue, metastable and unstable states are darker. The marker pole represents the negative U axis.



Following Gibbs' arguments, a (transparent) tangent plane has been placed on the surface at the point marked ■. The principal slopes of the plane denote the temperature and pressure at the point of tangency [$T = (\partial U/\partial S)_V$, $P = -(\partial U/\partial V)_S$], and the intercept of the plane on the pole gives the chemical potential ($\mu = G = U + PV - TS$).



Here the plane has rolled past the critical point and encountered the depression in the surface caused by the convexity change in the unstable region. Now a pair of coexisting tangent points are found, each having the same principal slopes (implying equivalent temperature and pressure) and each projecting to the same intercept on the pole (implying equivalent chemical potential). This illustrates Gibbs' geometrical analogy of phase equilibrium in a pure fluid.

characteristic from second derivative behavior.

Transparency was invoked to make certain structures visible that would otherwise have been obscured. The coexistence surfaces in the PVT and HSP sequences (yellow-green in figure 3, green in figure 16) illustrate this feature for static effects such as intersections and hidden surfaces. The transparency of the yellow tangent plane in the USV sequence (figures 7 and 8) permits viewing of the point(s) of tangency so as to confirm the response of the rolling plane to the curvature of the surface.

These images model the thermodynamic properties of pure fluids — one-component systems in the liquid and/or gaseous states. They are exact implementations of the ideas expressed by Gibbs in the second of his three papers.[3] Phase structures for multicomponent systems were the subject of Gibbs' third and best known paper[4] and comprise higher dimensional hypersurfaces that must be decomposed into three-dimensional components for visualization in the style of this work. Research to produce these more complex drawings is under way.

Details of The Technique

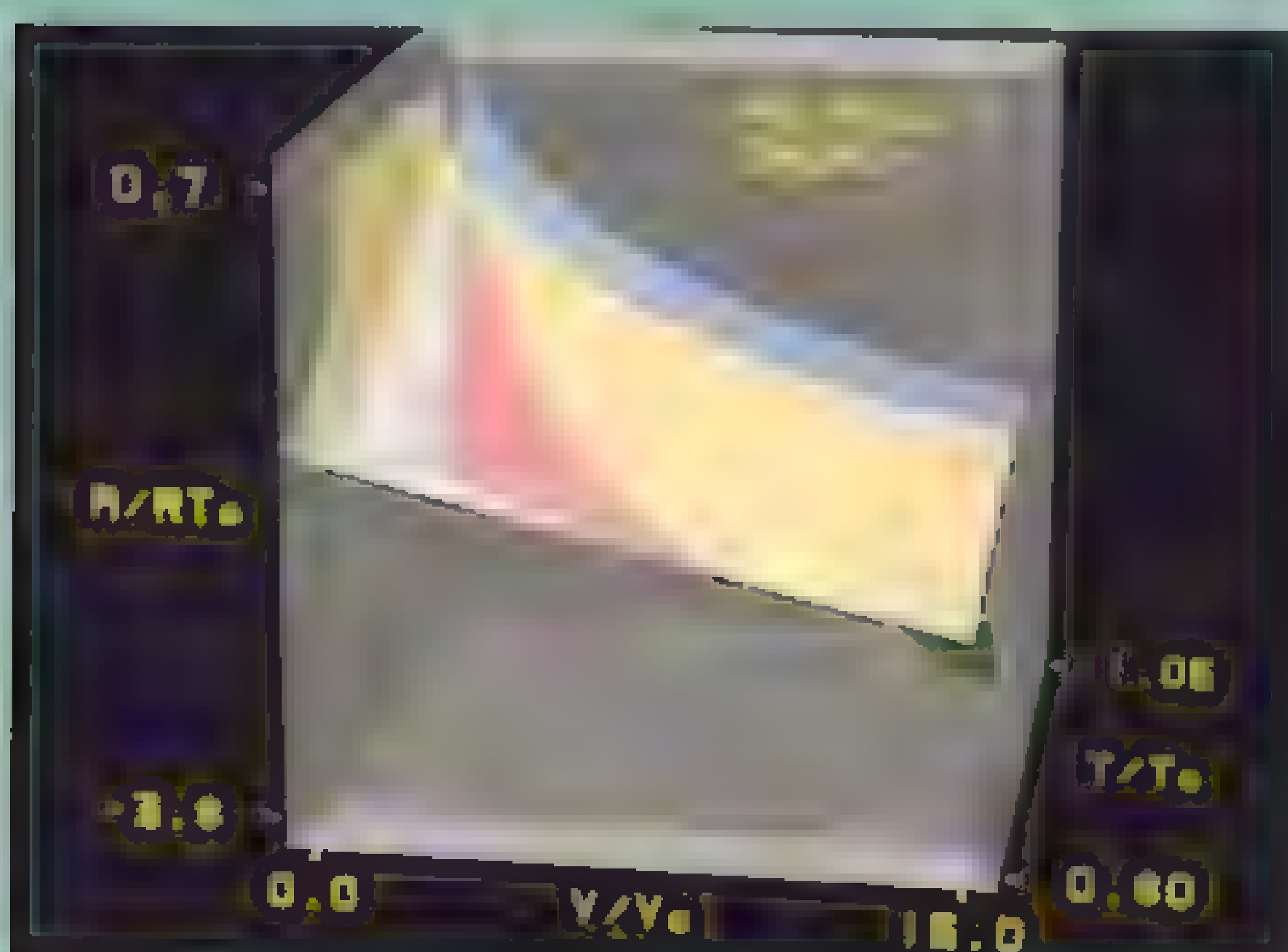
The present images were generated with a Silicon Graphics 3030 IRIS workstation. The 3030 has a resolution of 768 X 1024 pixels and is equipped with 24 bit-planes of display memory, thus permitting the simultaneous display of 16.8 million colors.

The rendering software was MOVIE.BYU, version 6.2.[5] Adaptation of the MOVIE code included a locally

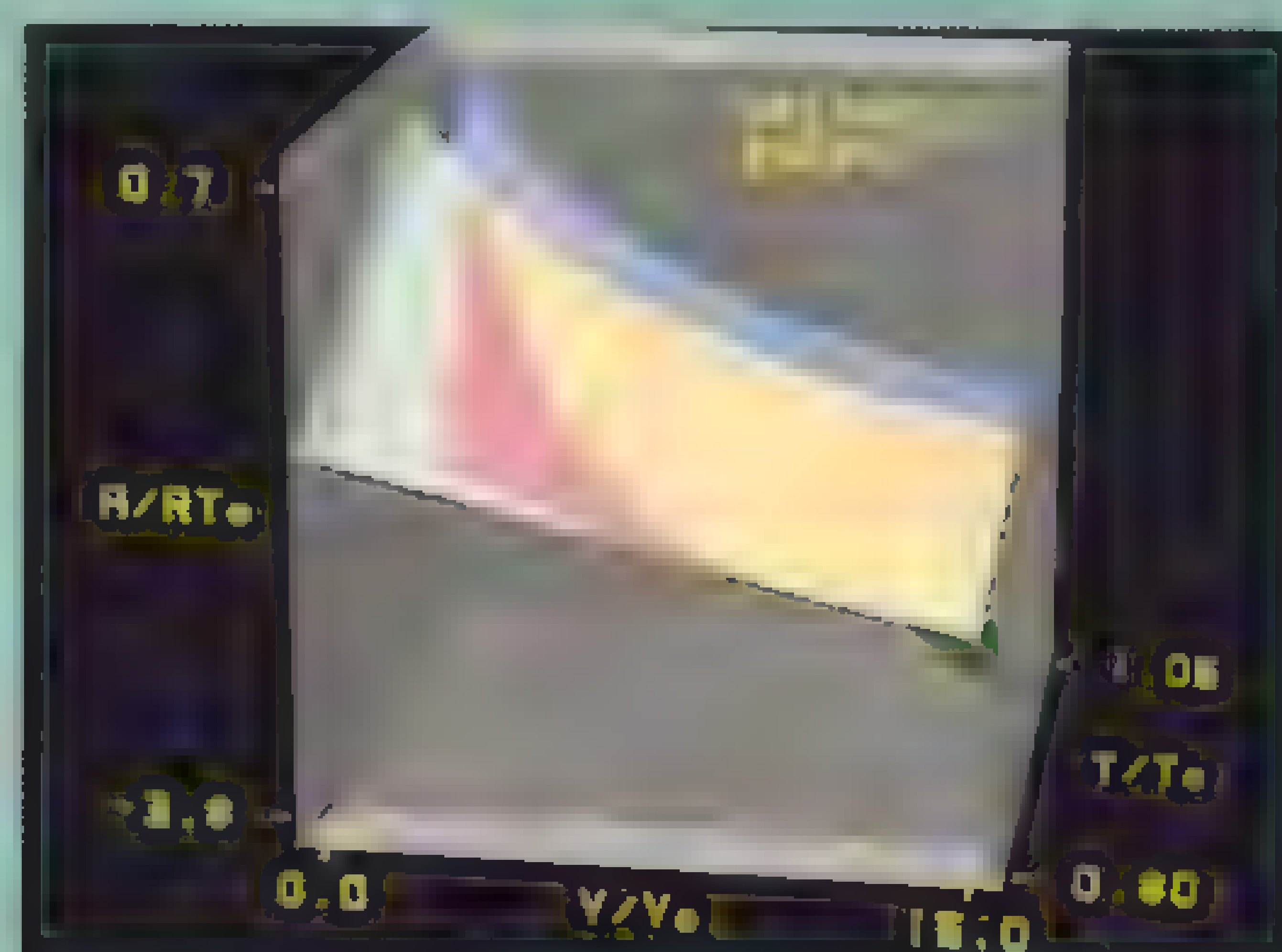
Helmholtz Energy-Temperature-Volume (ATV)

This form is a first Legendre transform of the USV function. Outside the unstable region it behaves as a saddle surface.

Here the unstable region has been removed.



The appended structure comprises subcritical, isothermal lines, each tangent to the ATV surface at two distinct points (volumes). Each pair of tangencies has a unique pressure [$P = -(\partial A/\partial V)_T$] and projects to a chemical potential common to the two points in the pair (μ is given by the intercept of a particular tangent line on the coordinate wall, V = 0).



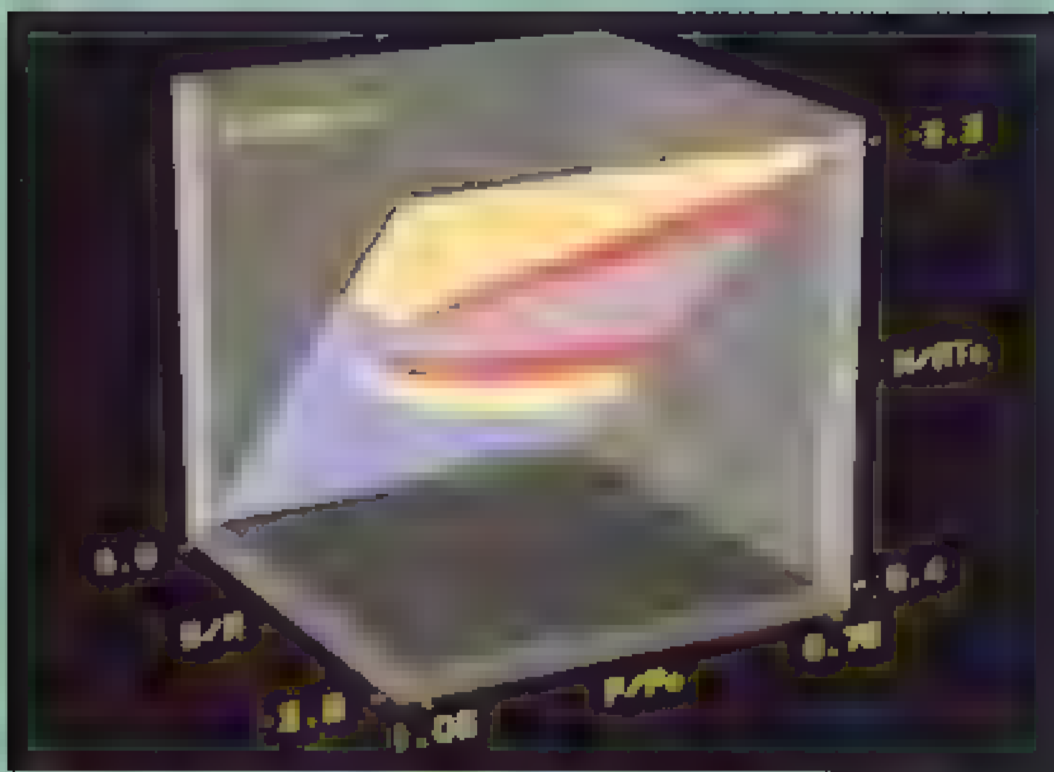
Here the stable and metastable liquid branches have been cut away to reveal the complete curve of common chemical potentials for the reference conditions chosen. This illustrates Gibbs' phase-equilibrium analogy transformed to the ATV coordinate system.

written 24 bit-plane IRIS driver, extension of the possible array sizes to allow for increased numbers of polygons, and minor modifications to the menu structure. The effects supported by MOVIE are well suited to the treatment of thermodynamic surfaces. The ability to specify the lighting model permits emphasizing the contours of the surface. The transparency option enabled us to produce unobtrusive coordinate planes and generate tangencies and overlays without hiding underlying structures. The "fringing" effect (not used in these images), where color changes in proportion to some computed quantity, is useful for conveying derivative or other dependent-variable information. Captioning was also carried out within the program to produce axis labels and properly oriented titles.

Maxwell's Model

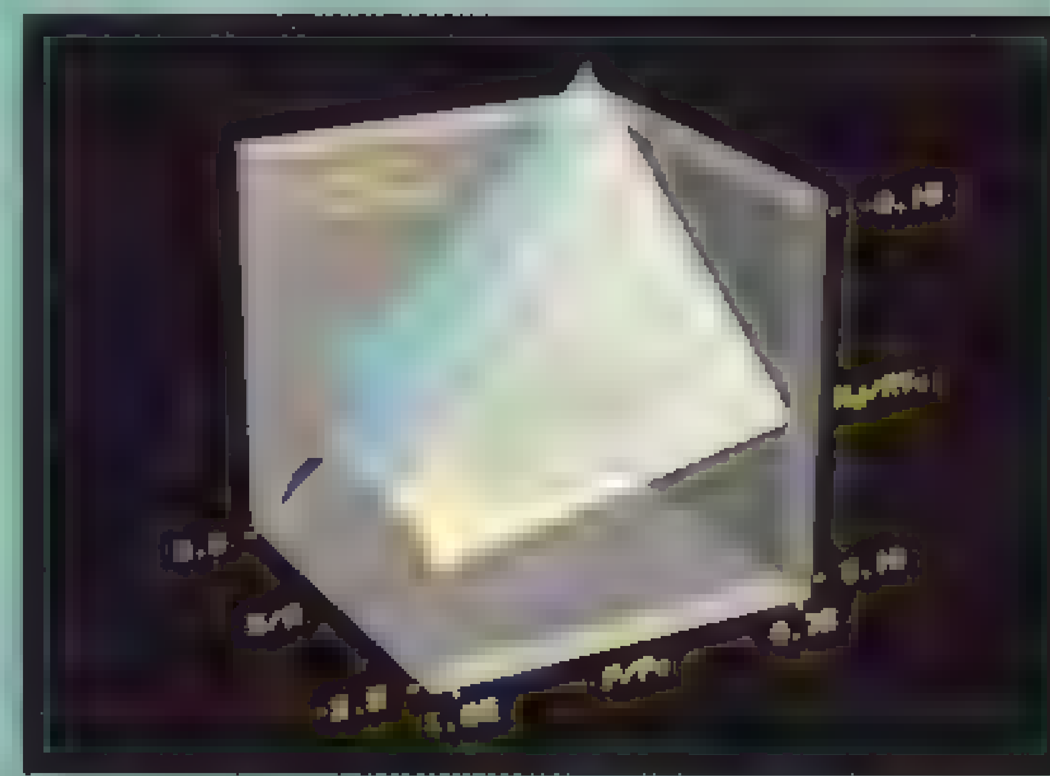
While Gibbs' ideas for using the geometry of a surface to model thermodynamic equilibrium were quite new in the latter decades of the 19th century, they would have been accepted slowly in England and in Europe had it not been for the efforts of James Clerk Maxwell, then head of the Cavendish Laboratory at Cambridge University. Maxwell's fascination was such that he spent an entire winter building a solid model of the USV surface for water. In a letter to Thomas Andrews, the discoverer of the continuity between liquid and vapor he wrote:[6] "I have just finished a clay model of a fancy surface showing the solid, liquid, and gaseous states, and the continuity of the liquid and gaseous states." Maxwell sent Gibbs a plaster cast of the model and kept a second copy

Enthalpy-Entropy-Pressure (HSP)



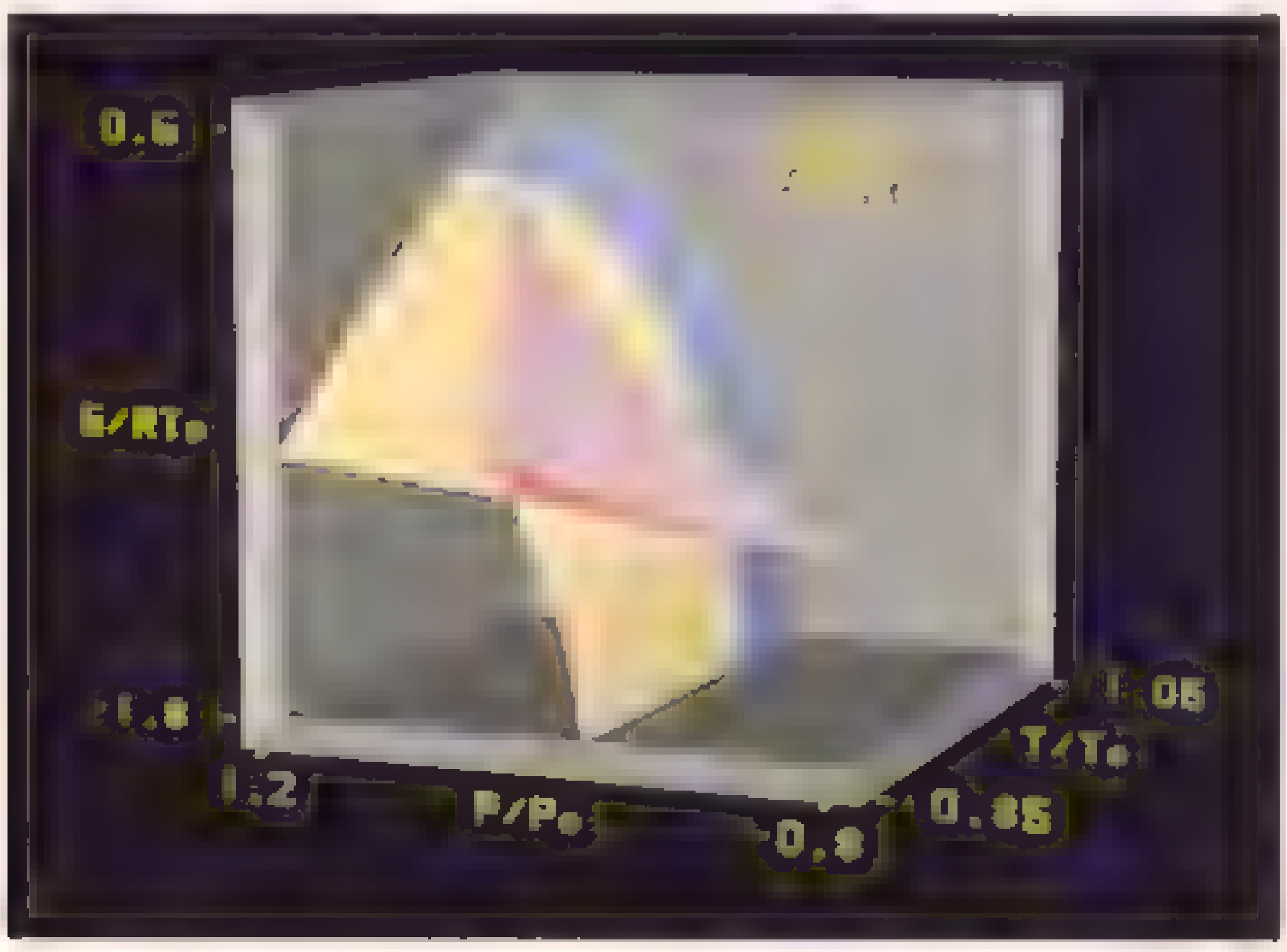
Enthalpy is another first transform of USV. Plotted in its unamended form, the surface appears flat at this magnification.

Features have been exaggerated by plotting the enthalpy difference
$H_d = H(S,P) - H_{ref}(S)$
The reference plane [$H_{ref}(S)$] is tangent to the enthalpy surface at the critical point. H_d is positive downward.

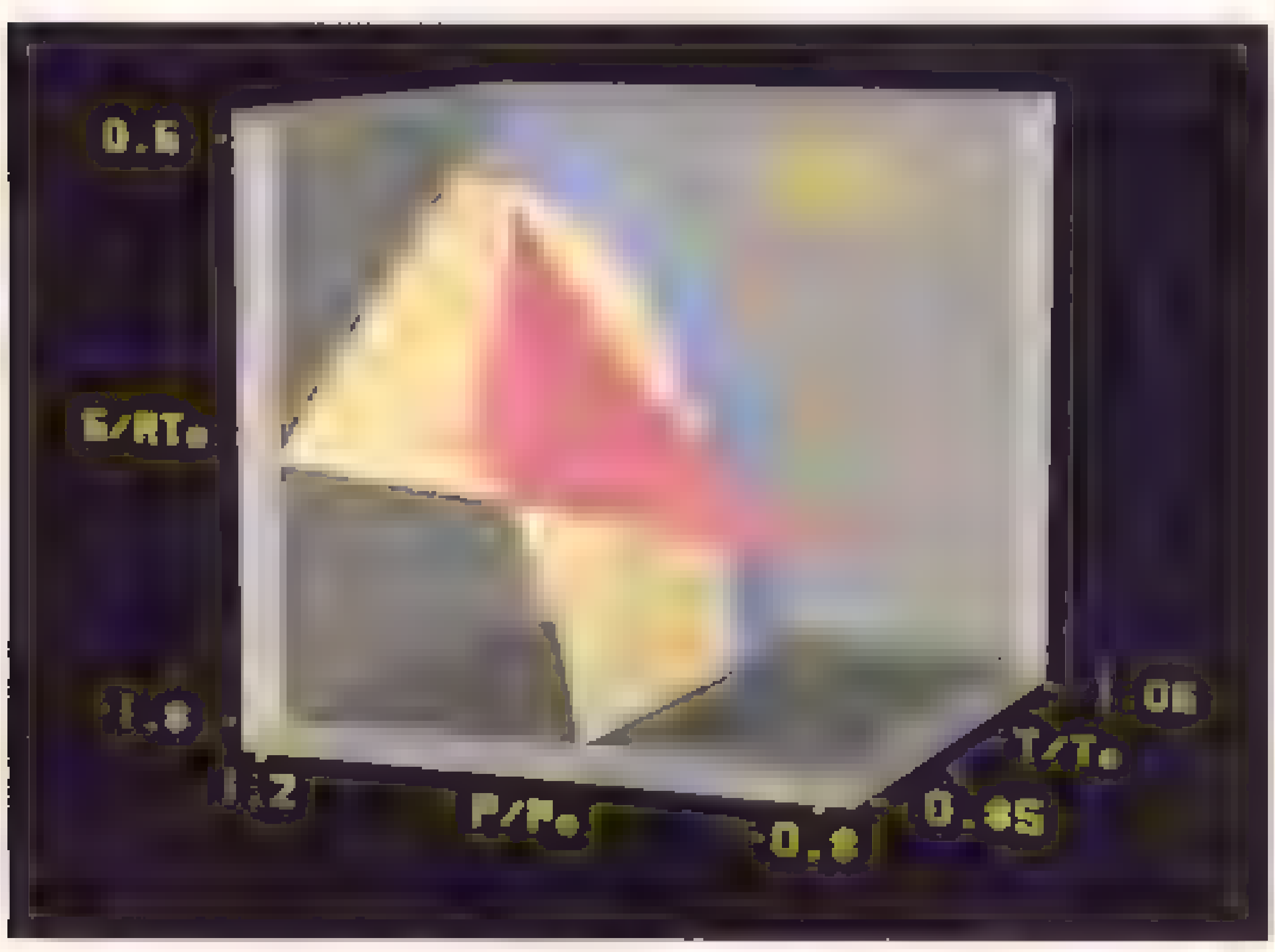


By analogy with the ATV surface, subcritical, isobaric tangent lines form an appended coexistence surface in this image. The points in each pair of tangencies have the same temperature [$T = (\partial H/\partial S)p$] and project to a common chemical potential — shown by the intercept of the tangent line on the coordinate wall, $S = 0$.

Gibbs Energy-Temperature-Pressure (GTP)



The Gibbs energy is a second transform of the USV function. The liquid and vapor branches intersect to give a single coexistence curve [$\mu(T) = G(T)$]. Much of the intersection is hidden in this image by the opaque unstable region above it.



With the unstable region removed, the intersection curve is visible over its entire length [$1.0 > (T/T_o) > 0.85$].

that is on display today in the Cavendish Laboratory. Gibbs' copy is preserved at Yale.

In the latter decades of the twentieth century, with the splendid visualization tools that we have at our disposal, illustrating Gibbs' verbal analogies is an interesting exercise in applied physical chemistry. Recognizing them a century ago, in the thin air of thermodynamic abstraction and with little or no possibility for visual verification, was a feat that few of us can imagine.

Acknowledgments

Consultation on color and other specifics in MOVIE.BYU was provided by Steven M. Herrnstadt (Iowa State University College of Design). An earlier rendering of the Helmholtz energy surface based on the van der Waals equation was performed by ISU graduate student Michael C. Schmitz.

Partial support for this work was provided by an unrestricted grant from the Camille and Henry Dreyfus Foundation and by matching funds from the National Science Foundation for engineering research equipment.

Kenneth R. Jolls is Professor in the Department of Chemical Engineering, Iowa State University. Daniel C. Coy is pursuing a Ph.D. at Iowa State.

1. In the drawings, R is the universal gas constant, and Po, Vo, and To are the values of the pressure, volume, and temperature at the vapor-liquid critical point.
2. Peng, D-Y., and D.B. Robinson, *Industrial and Engineering Chemistry, Fundamentals*, 15 (1976), p.59
3. Gibbs, J.W., *Transactions of the Connecticut Academy*, II, 382, December (1873), p. 382.
4. Gibbs, J.W., *Transactions of the Connecticut Academy*, III (October 1875-May 1876), pp. 108-248; (May 1877-July 1878), pp. 343-524
5. "A General Purpose Computer Graphics System," operating guide for MOVIE.BYU, version 6, Department of Civil Engineering, Brigham Young University, Provo, Utah (1987).
6. J.C. Maxwell to Thomas Andrews (November 1874), in P.G. Tait and Alexander Crum Brown, "Memoir of Dr. Thomas Andrews," *Scientific Papers of the Late Thomas Andrews*, P.G. Tait and A.C. Brown, eds., MacMillan and Co., Ltd., London (1889), pp. ix-lxii.

PRODUCT BRIEFING

PostScript Compatible Interpreter for the Personal IRIS

Under the terms of an Independent Software Vendor agreement with Silicon Graphics, Custom Applications, Inc. (CAI) will provide a PostScript language compatible interpreter for the Personal IRIS workstations. With the product, PostScript will be interpreted in the workstation, rather than in the printer.

Users will be able to access over forty distinct printers, plotters, and film recorders. A facility for providing variable resolution raster file output will also be available. The interpreter will use the Agfa Compugraphic intelligent font scaling subsystem known as "Intellifont" for all font manipulations. PostScript support will provide a foundation for color publishing uses.

For more information, contact: Mark Hastings, Custom Applications, Inc., Billerica, Massachusetts, (508) 667-8585.

New 4D/300 Project Supercomputers

On April 2, 1990 Silicon Graphics announced a new product line of Project Supercomputers. The 4D/300 line offer a dramatic increase in system throughput over the existing 4D/200 product line, while maintaining 100 percent binary compatability with the entire SGI product family.

The 4D/300 line, an extension of the IRIS POWER Series™, includes five major enhancements over the existing 4D/200 product line: 33MHz RISC processors; IPI2X™ disk subsystem; the POWER Channel™ I/O Processor; enhancements to the IRIX™ operating system including REACT™ realtime extensions; and high-density 4Mbit DRAM memory chips.

The 4D/300 product line offers I/O and memory capabilities that were previously available only in the mini-supercomputer class of machines, systems that cost five to ten times more.

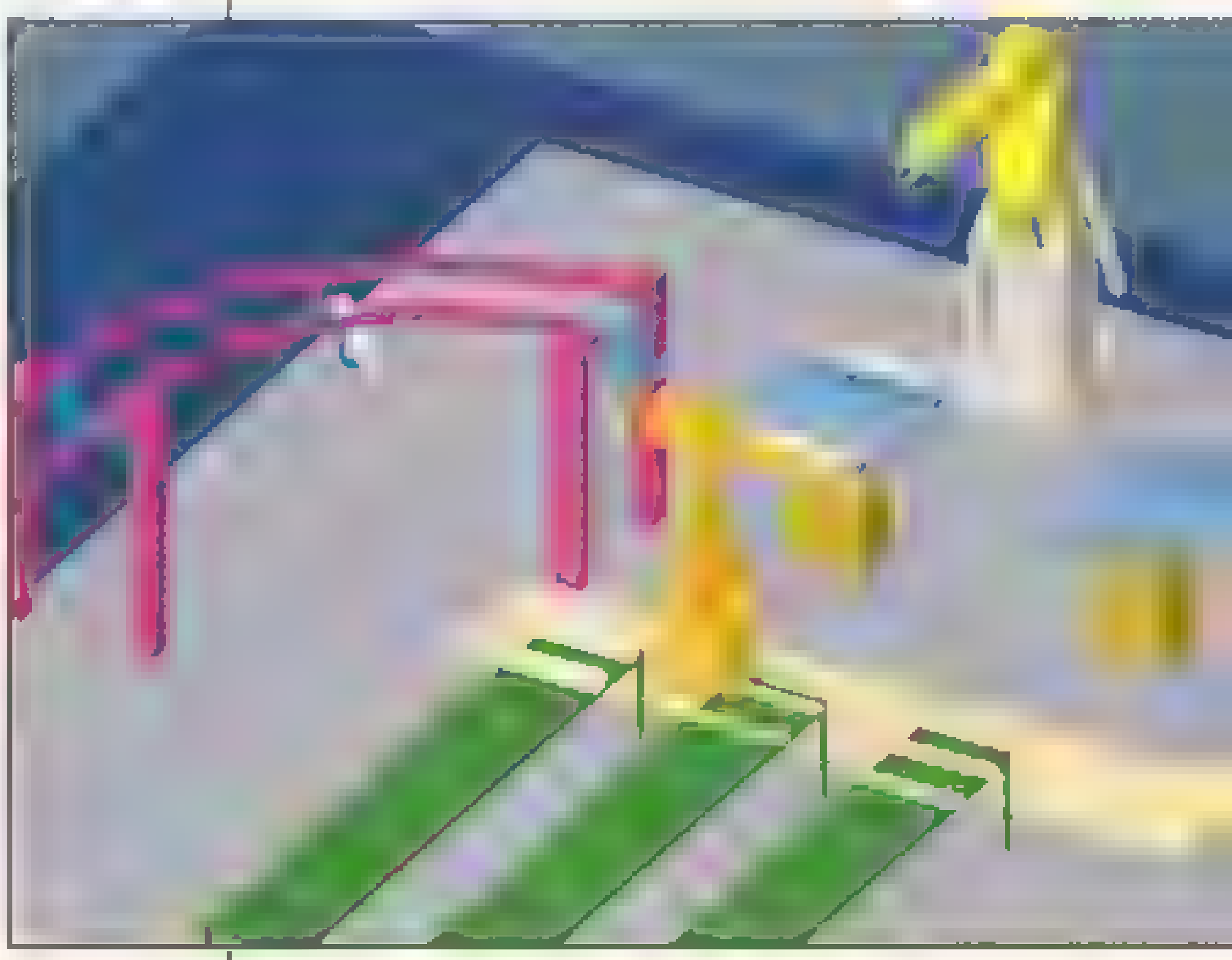
For more information, contact: Silicon Graphics, (415) 960-1980.

Analog Video Mixer for Computers

RGB Spectrum has introduced a High Resolution Video Mixer (HRVM) for mixing computer video signals in real time. By combining the power of more than one computer, the HRVM allows real-time generation of images or scenes too complex for a single system.

The product combines the video output from two genlocked workstations or graphics systems displaying up to 1280 x 1024 pixels. One is used to calculate the foreground image, while the other calculates the background. The HVRM accepts both video outputs and combines the two using a chroma key. For complex 3D scenes, multiple workstations may be connected by using two or more HRVM units.

For more information, contact: Carol Fogel, RGB Spectrum, Berkeley, California, (415) 848-0180.



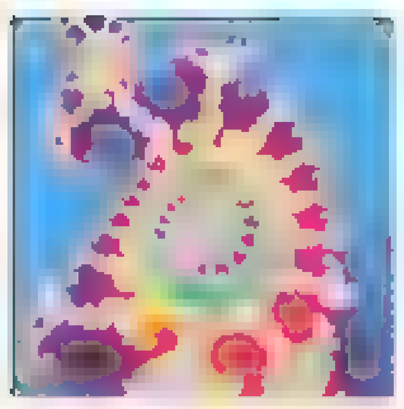
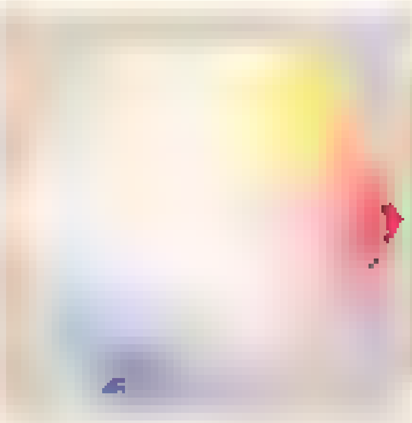
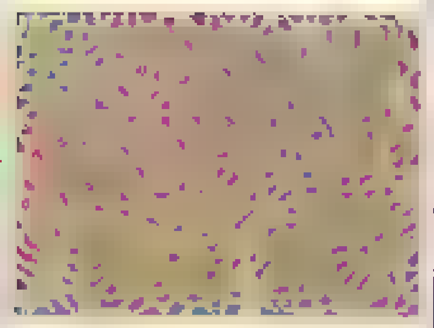
Tecnomatix Receives Major Order from Ford Motor Company

Tecnomatix Technologies announced a major order from Ford Motor Company Worldwide Users Group for ROBCAD workstations. The ROBCAD workstation features a software package for design, simulation, and off-line programming of robots. These robots assist in the flexible automation of manufacturing industries.

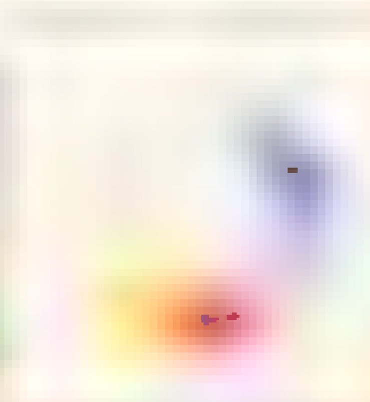
ROBCAD assists the implementation of these CAM engineering systems by allowing an operator to model, modify, and evaluate various automation concepts. A detailed design of the system may be generated by using ROBCAD's library of robots, automation components and user CAD files. The operation of the system can be simulated to optimize component selection, placement, motion control sequence, and cycle time. The automation system is programmed offline by downloading ROBCAD generated programs to the various device controllers.

For more information, contact: Harel Beit-on, Tecnomatix, Novi, Michigan, (313) 471-6140.

COMMUNITY FORUM






Call for Ideas — National Neural Circuitry Database

The Institute of Medicine of the National Academy of Sciences has formed a study committee to examine the feasibility of establishing a National Neural Circuitry Database (NNCD). The committee's report is scheduled to be released in January 1991. Under consideration is a NNCD that would contain textural and graphic information on the anatomy, physiology, chemistry, and pharmacology of rat, monkey, and human brains. The database would, through 2 and 3-D graphic displays, permit the user to rotate or slice the images in order to access information regarding brain structure and function. Such a database could also allow for the electronic storage and transmission of neuroscience data. In addition, the database might function as a vehicle for collaboration on basic and clinical neuroscience research, and for data sharing.

Individuals who wish to offer ideas may do so, in writing (two typed pages maximum). Deadline for submissions is May 31, 1990. Send to: Constance Pechura, Ph.D., National Academy of Sciences, Institute of Medicine, Room 324, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Visualization in Biomedical Computing Conference

The first Visualization in Biomedical Computing Conference (VBC) will be held May 22-25, 1990 at the Ritz-Carlton Buckhead Hotel in Atlanta, Georgia. The conference is hosted by the Georgia Institute of Technology and Emory University School of Medicine. Sponsors include the IEEE Computer Society and the National Science Foundation, among others.

The goal of the conference is to define and promote the emerging science of visualization by bringing together a multidisciplinary, international group of researchers, scientists, engineers, and toolmakers engaged in all aspects of scientific visualization, and, particularly, visualization in biomedical computing.

For further information, contact: Continuing Medical Education, Emory University School of Medicine, 1440 Clifton Road, NE., 104 WHSCAB, Atlanta, Georgia 30322, (404) 727-5695.

Speakers Wanted for Women and Mathematics

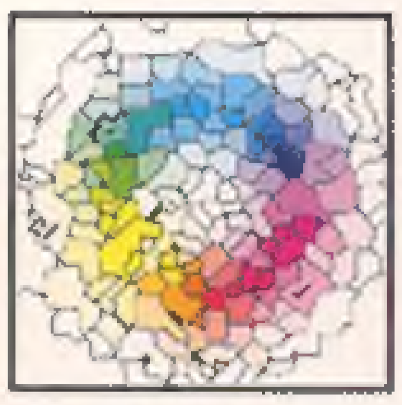
Women and Mathematics, a speakers program of the Mathematical Association of America, is seeking professional women in science and engineering to visit high school and junior high classes, clubs and career fairs. Speakers discuss their jobs, the college education that is required and necessary high school level preparation.

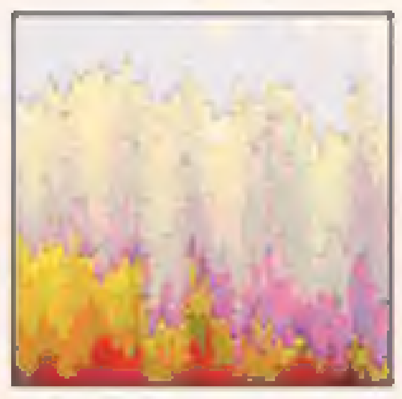
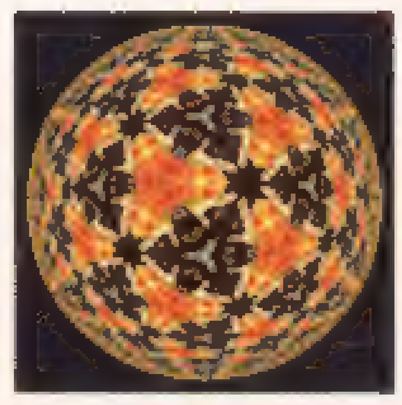
For more information, contact: Alice J. Kelly, National Director, Women and Mathematics, Mathematics Department, University of Santa Clara, Santa Clara, CA 95053: (408) 554-6811 or *akelly@scu.BITNET*

Worldwide Art Contest Call for Participation

The seventh annual Conference of the Australian Computer Graphic Association, Ausgraph 90, has issued a call for participation in their Art and Video Program. Submissions will be considered for artwork and installations for an international exhibition of art and technology, papers for the Arts Stream of the conference, and animations and digital video for the National Art and Animation Competitions. The deadline for entries is June 1, 1990.

Total prizes will amount to several thousand dollars to be awarded by Pansophic of Australia and others. For more information, contact: Paul Brown, Ausgraph 90, P.O. Box 29, Swinburne Institute, Parkville, Victoria 3052, Australia. Telephone: 61 (3) 387-9955, FAX: 61 (3) 387-3120.


SIGGRAPH '90

The 17th International Conference on Computer Graphics and International Techniques will be held in Dallas, Texas, August 6-10. The conference includes panel discussions, a tradeshow, an art show, technical papers, a film and video theater, and an exhibit of hypermedia. For conference information, contact: SIGGRAPH '90, Conference Management, Smith, Bucklin, and Associates Inc., 111 East Wacker Drive, Suite 600, Chicago, IL 60601, (312) 644-6610.

PARIS CITEÉ The International Competition for Creative Technology

The aim of this international event is to unite the worlds of artistic creation and industrial innovation, concentrating on image, sound and music, language, and audiovisual production. This "summit meeting" of science, industry and the arts includes an international competition open to artists, companies, and engineers, an exhibition of the latest industrial and artistic innovations using new technologies, and a gala event at the Theatre des Champs-Elysees.

PARIS CITÉ takes place June 15-25, 1990 in Paris, France. For more information, contact: Francis Balagna, Secretaire General de PARIS CITEÉ, Mairie de Parisadac, 27, quai de la Tournelle-75005, Paris, France, (phone) 43.26.29.99, (fax) 43.29.38.01.

Visualization '90

Visualization '90 will be held October 23-26 in San Francisco, California. The conference is concerned with all aspects of visualization, with a special focus on interdisciplinary techniques.

The submission deadline for panel proposals is May 1. Contact Georges Grinstein at (508) 934-3627. Tutorial proposals also have a May 1 deadline, contact David Salzman at (609) 520-2000. The same deadline applies to case studies. Contact Paul Hazan at (301) 953-5364. Papers are due May 15, contact Arie Kaufman at (516) 632-7441. Demonstrations will be due June 1, contact Val Watson at (415) 604-6421. The conference is sponsored by IEEE Computer Society, Technical Committee on Computer Graphics.

Supercomputing '90

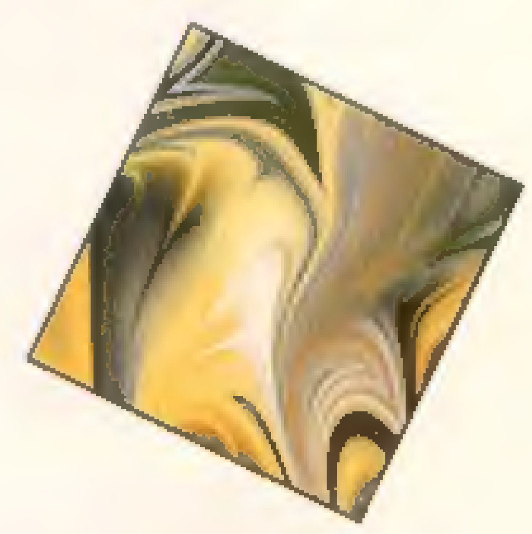
This conference, which is jointly sponsored by IEEE Computer Society and ACM SIGGRAPH, takes place November 12-16 at the New York Hilton, New York City. The conference brings together supercomputing system researchers, designers, managers, computational scientists, and engineers. It will include a technical program of invited and contributed papers, tutorials, poster sessions, vendor and research exhibits, and product briefings and demonstrations.

For more information contact: Joanne L. Martin, General Chairperson at (914) 945-3285 or *jlmart@ibm.com*.

Second International Symposium on Electronic Art

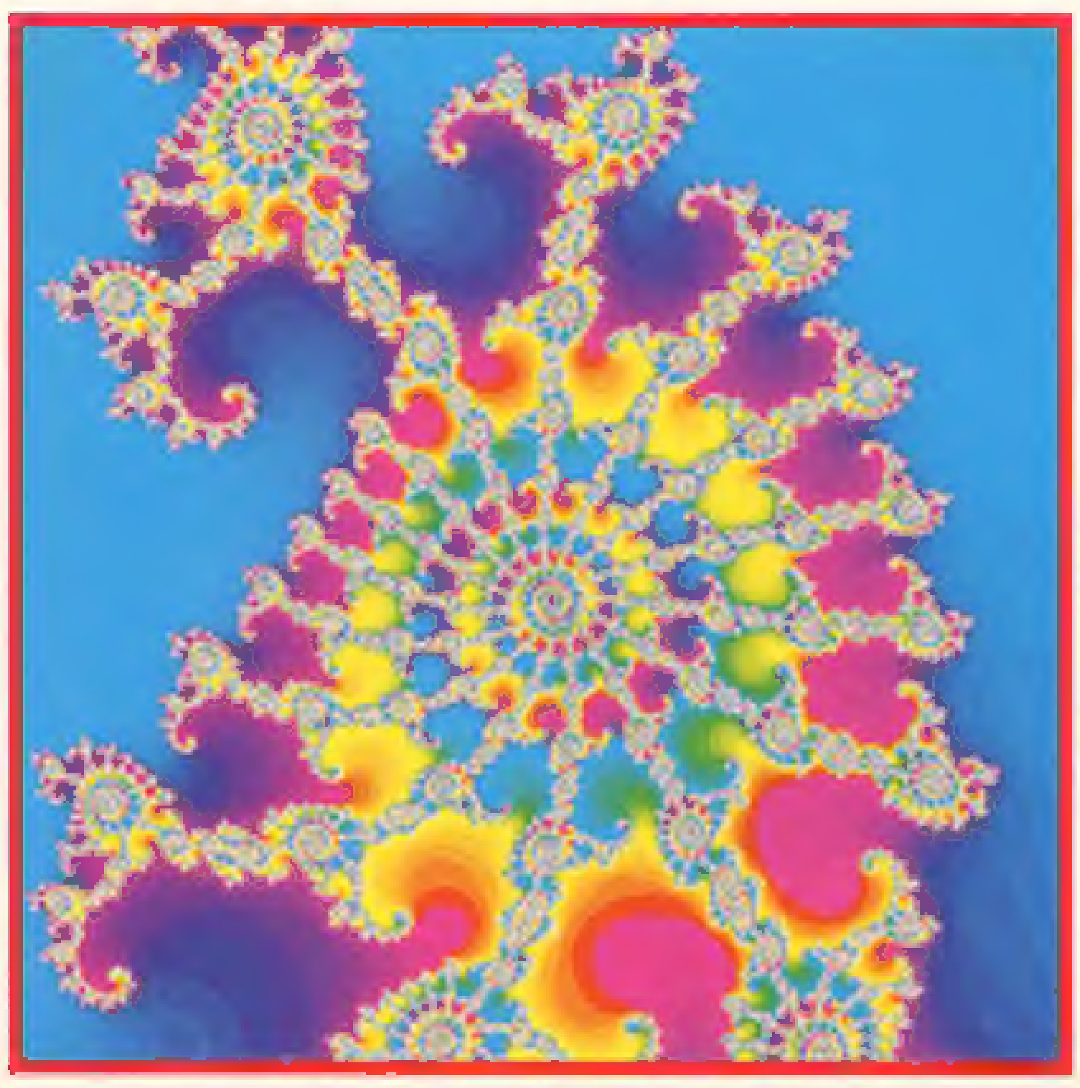
This year's conference, held Nov. 12-17 in Groningen, Holland, will feature a scientific symposium, workshops on computer art and music, concerts, a film and video show, and an exhibition.

For more information, contact: SISEA, Westerhavenstraat 13, 9718 AJ Groningen, The Netherlands, (phone) 31-50-138160, (fax) 31-50-138242 or *scan@hgrrug5 .BITNET.*



Please send submissions to Community Forum to IRIS Universe, *Mail Stop 415, Silicon Graphics, Inc., 2011 N. Shoreline Blvd. Mountain View, California 94039-7311*

COMING ATTRACTIONS



Coming in Future Issues of *IRIS Universe:*

The IRIS and the Human Genome Project
A new three billion dollar project to decipher the entire DNA structure of a single human cell will require computer systems that can handle large volumes of information at high speed, provide interactive performance, and are easy to use and maintain.

Geo Sciences: the Present and the Future
A series of articles. The first will focus on the petroleum industry where visual processing is an important and useful new tool.

Synthetic Digital Environments
A day in the life of a parallel universe. Virtual Environment, Virtual Reality, SDE, call it what you will, the practical applications present a vast array of new challenges for visual processing.

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Parallel Programming *4.5 days*	May 21, 1990 Jul 23, 1990 Oct 22, 1990	not available
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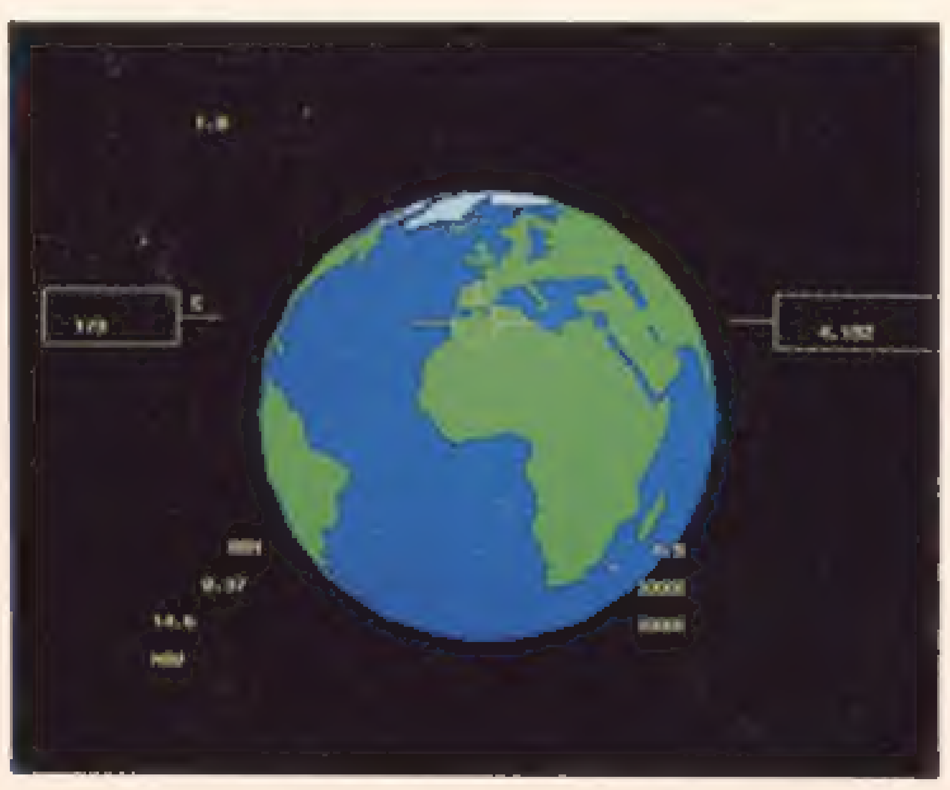

For information or a demonstration,

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